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Evaluating the ability of the NE system to predict growth performance and energy utilization of growing pigs

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Evaluating the ability of the NE system to predict growth performance and energy utilization of growing pigs

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DEDICATION

To my parents and my wife.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Page

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ABSTRACT

The net energy (NE) system describes the useful energy for growth better than the metabolizable energy (ME) system. Therefore, the NE system should demonstrate a more predictable animal response when a wide range of ingredients are used, but this fact needs to be demonstrated in practice. The objective of this thesis was to evaluate the NE system in diets containing a diverse set of ingredients. Two experiments were conducted: the first experiment consisted of comparing growth performance, carcass characteristics and the efficiency of dietary energy of 2,054 pigs housed in pens in a commercial research barn. Pens were assigned to one of 5 different feeding regimes. A corn-soybean meal control diet served as the basis to establish baseline levels of ME and NE for both programs. Two treatments added DDGS to the control diet formulated using the ME or the NE system and another set of diets that added both DDGS and corn germ meal and was formulated using the ME or the NE system. Diets formulated with the ME and the NE system maintained overall whole body growth performance. However, carcass parameters (except carcass G:F and lean percentage) declined with the addition of co-products especially in diets formulated with the ME system. The intake of NE decreased in the same fashion that carcass gain did, suggesting a relationship between energy intake and energy retention. Additionally, NE per kg of carcass was similar among diets suggesting that NE is better at explaining carcass results. The second experiment compared the apparent total tract digestibility (ATTD) of energy and of nutrients and the nitrogen retention (NR) of 40 gilts. The 5 dietary treatments included a control corn soybean meal-based diet, a diet similar to the control diet but containing 6% each of corn distillers dried grains with soubles (DDGS), corn germ meal and wheat middlings with NE constant relative to the control diet, or allowed to decline. A last set of diets contained 12% each of the same co-products and NE held constant or allowed to

decline. The diet digestion containing increasing levels of co-products and formulated to a constant NE concentration resulted in the expected equivalence of DE, ME and NE concentration. However, NR declined on all co-product diets. In conclusion, adopting the NE system does not imply a decline of productive parameters compared to the ME system, because in no-instance was the ME system superior to the NE system.

CHAPTER I

LITERATURE REVIEW

Introduction

The goal of pork production is to maximize the expression of the genetic potential of the growing pig to gain lean and adipose tissue at an optimal cost. Dietary energy is essential in this process because it is the fuel the pig needs to maintain physiological functions, and for the synthesis of animal products. Additionally, because supplying dietary energy to pigs is the most important cost in swine production (Noblet, 1994; Stein and Shurson, 2009; Gutierrez and Patience, 2012), there is great interest in making energy utilization cost effective. Energy systems are used in swine production to provide dietary energy in an efficient way. These systems assign energy concentrations to diets according to energy utilization by the pig. Currently in the U.S, the ME system is widely used, but the NE system is attracting more interest due to its theoretical potential to more accurately measure the true energy needed by the pig.

The objectives of this review are i) to explain the basis for energy systems ii) to describe the existing energy systems iii) and to compare the ME and the NE systems as a way to use dietary energy effectively.

Basis for energy systems

Laws of thermodynamics:

"Energy is defined as the potential capacity to perform work. There are several forms of energy: chemical, mechanical, kinetic, positional, electrical and heat. The first law of thermodynamics states that energy can be neither created nor destroyed, but can be transformed

from one form to another. The second law states that all forms of energy are convertible to heat, so the driving force in all systems is to release energy as heat"

Animal nutrition has applied the laws of thermodynamics, to measure and calculate energy supply and energy utilization of pigs (Baldwin, 1995).

Characteristics of the energy supply

The energy content of a feedstuff is determined by the organic matter it possesses; specifically carbohydrates, lipids and proteins. It is estimated that after complete oxidation, each gram of these molecules yield 4, 9 and 5 calories, respectively.

Carbohydrates are the major energy source in most practical diets for swine. They include highly diverse biological molecules having the formula $C_n(H_2O)_n$, in which the molar ratio of carbon, hydrogen and oxygen is 1:2:1 (Ross, 2014). There are carbohydrates containing 3 to 6 carbon atoms called monosaccharides, divided into two chemical functional groups (aldehydes and ketones) and subdivided by isomers based on the position of an hydroxyl group on the second carbon (stereocenter). Carbohydrates can be classified based on their degree of polymerization as monosaccharides, disaccharides, oligosaccharides and polysaccharides (Cummings and Stephen, 2007). Polymerization is achieved by the presence of glycosidic linkages (alpha, α or beta, β).

The most common carbohydrates found in swine feedstuffs are polysaccharides in the form of starch (glucose polysaccharide with α 1-4 and α 1-6 bonds) and non-starch polysaccharides including cellulose, hemicellulose, β glucans, pectins and gums (polymers of glucose and other monosaccharides linked with α and β bonds), oligosaccharides such as galacto-, fructo- and mannan-oligosaccharides (small number of monosaccharides linked with α

and β bonds,), and sugars such as sucrose, lactose and maltose (disaccharides with α and β bonds).

Analytical methods to estimate the carbohydrate content in swine feedstuffs are usually divided into those quantifying cell walls or cell contents. Determination of cell content carbohydrates include starches and sugars, while determination of cell wall carbohydrates include determination of acid and neutral detergent fibers (ADF and NDF), non-starch polysaccharides (NSPs), soluble dietary fiber, and total dietary fiber (TDF). Assays that determine ADF, NDF and TDF content include lignin, which is a non-carbohydrate molecule (Lupton, 2010).

Lipids are the most energy-rich molecules in swine diets. Although they belong to a set of different molecules, lipids as energy providers are basically fatty acids. Fatty acids are long hydrocarbon chains with various lengths and degrees of unsaturation terminated with carboxylic acid groups (Berg, 2007). They are normally classified according to the number of carbons (short, medium and long chain fatty acids) and to the number of double bonds or unsaturations (unsaturated, mono-unsaturated and polyunsaturated). Fatty acids in feed ingredients rarely come in free form; they usually are bound to glycerol through ester linkages forming triglycerides, and in a minor proportion, phospholipids when glycerol is also bound to a phosphate group. The gross energy from fatty acids increases slightly as fatty acids become longer and saturated.

The most common method to determine ingredient or dietary fat content is by solvent extraction. Fat is particularly soluble in non-polar organic solvents such as hexane, diethyl ether or chloroform. However, membrane-associated lipids are more polar and require polar solvents such as ethanol or methanol to disrupt hydrogen bonds or electrostatic forces (Shahidi and

Wanasundara, 2008). In this manner, they can be separated from surrounding components and measured as a percentage or a concentration. However, typical extraction methods do not completely extract fatty acids, especially when fat is present as salts of divalent cations or linked to various carbohydrates or proteins (NRC, 2012). This problem can be solved with a previous acid hydrolysis. Hydrochloric acid and heat are able to destroy the binding of fat with other molecules, so that "total fat concentration" can be determined. Fatty acid profiles can be determined using high-performance liquid chromatography (HPLC) or gas chromatography (GC).

Proteins are biological molecules composed of amino acids. Amino acids are molecules composed of a central carbon bonded to an amine ($-NH_2$) group, a carboxylic group (-COOH) and a variable side chain that is specific to each amino acid. There are 20 main amino acids present in feed. Nitrogen content is a function of the quantity of amino acids, and the balance of individual amino acids. The commonly-used conversion factor of N × 6.25 ([1/16]*100 = 6.25), derives from the assumption that the average content of nitrogen in protein is 16%. Analytical methods to obtain nitrogen concentration are the Kjeldahl method and the thermal combustion method (AOAC, 1990). Amino acids are determined by HPLC following acid or alkaline hydrolysis, GC or ion exchange chromatography among others.

Energy utilization by the growing pig

Energy required functions account for the energy expenditure of the pig. Within those functions digestion and metabolism are vital for transporting and transferring energy from the diet to forms the animal can use. Therefore, since an energy investment is necessary to capture

new energy, a minimum energy available should be maintained to guarantee the energy flow (Pascal and Boiteau, 2011).

Dietary energy flow “Transferring dietary energy to ATP, animal proteins and lipids”

Digestion and metabolism

In the process of digestion, polymers of carbohydrates, lipids and proteins are broken down in the gastrointestinal tract by chemical-enzymatic processes to monosaccharides, short chain fatty acids (products of microbial metabolism), monoacylglyrerols, fatty acids, amino acids, and very small peptides. These molecules can be absorbed by the intestinal epithelium, thereby allowing the absorption of energy. In typical pig diets, 70 to 90% of the original dietary energy is absorbed following these digestive processes (Milgen, 2006). This range depends on the composition of the diet, specifically the proportion which is in the form of dietary fiber (Noblet and van Milgen, 2004). As a general rule, as fiber content increases, less energy is absorbed by the gastrointestinal tract. This occurs for two main reasons. First, the absorbable energy from the fiber is mediated by microbial fermentation, not by enzymatic digestion (Zijlstra et al., 2012). As a result, only short chain fatty acids are available for metabolism. These molecules produce less energy than the carbohydrate monomers that compose fiber (Hungate, 1966; Bakker, 1996). At the same time, the capacity to ferment fiber depends substantially upon the type and source of dietary fiber (Stanogias, 1985). In general terms, soluble fiber is fermented in greater proportions than insoluble fiber (Bakker, 1996; Zhang et al., 2013). Additionally, dietary fiber can reduce the digestibility of other dietary components (Urriola et al., 2013; Gutierrez et al., 2013).

Another factor that affects digestion of energy yielding molecules is the degree of saturation of fatty acids; saturated lipids are typically less digestible than unsaturated lipids (Wiseman et al., 1990).

Ultimately, the non-absorbed energy fraction that is eliminated in feces corresponds to unabsorbed proteins, fat, non-fermented fiber, and non-absorbed VFA (Bastianelli et al., 1996) and microbial mass. Additionally, after digestion some energy is eliminated in the form of heat, and in gases produced by fermentation, such as methane and another products.

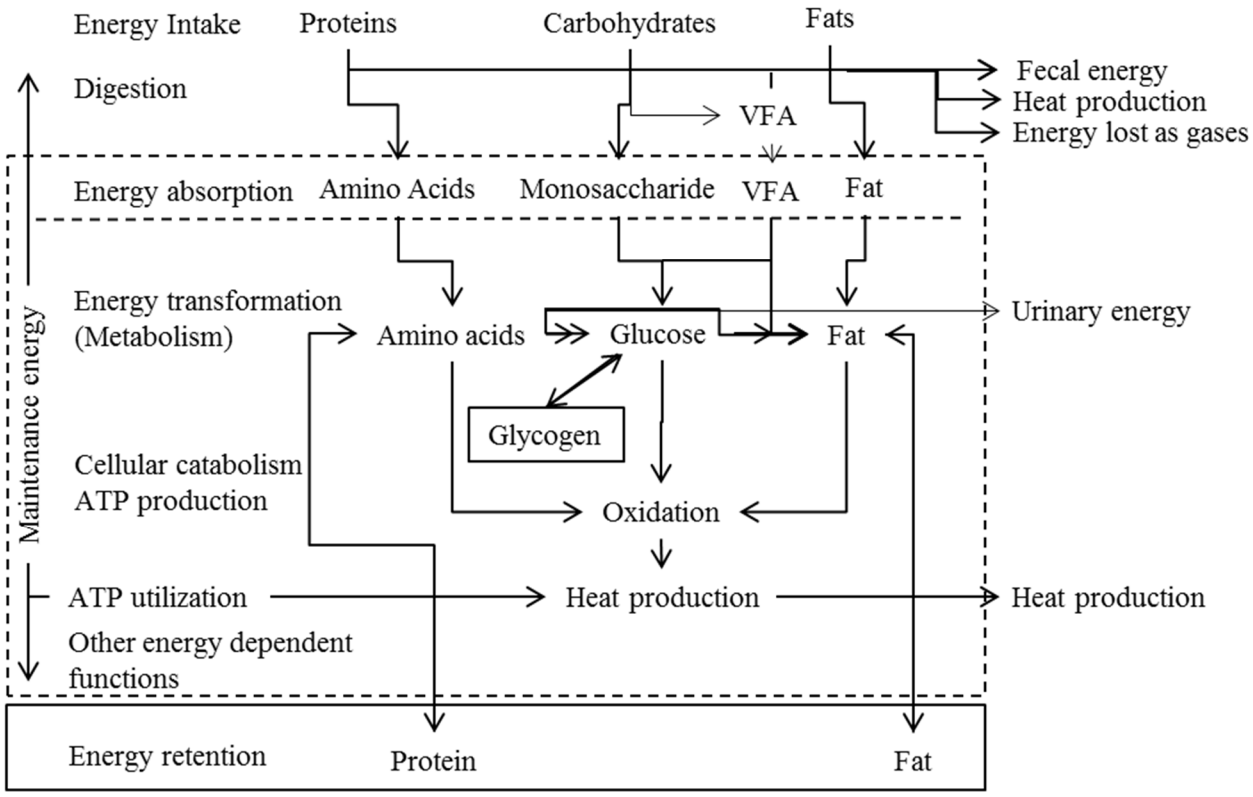

Figure 1.1 Energy flow in the growing pig adapted from (Chwalibog et al., 2004)

Energy metabolism

Once absorbed, energy containing molecules enter the nutrient pool exchange. The nutrient pool exchange handle with the immediate dynamics of nutrient supply, nutrient requirements and deal with nutrient transfers between different organs. It represents all possible metabolic transactions including several pathways (Milgen, 2006).

Carbohydrates (mainly glucose) are principally substrates for energy metabolism (Cummings and Stephen, 2007). Therefore, the first utilization method is glycolysis and phosphorylative oxidation to synthetize ATP. A second method is the synthesis of glycogen in liver and muscle. Glycogen will typically be constantly synthetized because it serves as an immediate short term energy supply. A third way is the synthesis of fatty acids from the transformation of glucose to acetyl-CoA in adipose tissue via the de novo pathway (Halas et al., 2004; Mersmann and Smith, 2005). In growing animals, lipids are mainly stored as triglycerides. However, they also can be transformed into other molecules such as phospholipids and cholesterol esters or they can be oxidized to synthetize ATP through the β-oxidation pathway.

The major metabolic fate of amino acids is protein synthesis; however, they can also be catabolized in the liver and the gut by deamination and used to synthetize glucose (Stoll, 2005) and/or fatty acids (Mersmann and Smith, 2005). Part of the digestible protein fraction will be deposited as body protein (PD, g/d). The remainder will be deaminated so that the carbon-chain can be used for other energetic purposes (van Milgen et al., 2008). Therefore, they can be stored as glycogen and triglycerides. Like carbohydrates and lipids, amino acids can also be oxidized to produce ATP. In amino acid catabolism, some energy is lost in the urine. Finally, although not considered part of energy metabolism, some amino acids are utilized as precursors for numerous

functional end products including glutathione, nucleosides, glucosamine, creatinine, nitric oxide, polyamines, etc.

As described before, the end-product of oxidation of glucose, fatty acids, amino acids and some metabolic intermediaries derived from these molecules is the synthesis of ATP (state 2 to state 1; figure 1.2). Production of ATP is vital because it couples all energy required reactions in the pig (Baldwin, 1995; Rolfe and Brown, 1997). On the other hand, energy retention can also take place with the accretion of tissue mainly in the form of lipids, proteins and glycogen (although the capacity to store glycogen is very limited and therefore is often ignored in energy retention calculations).

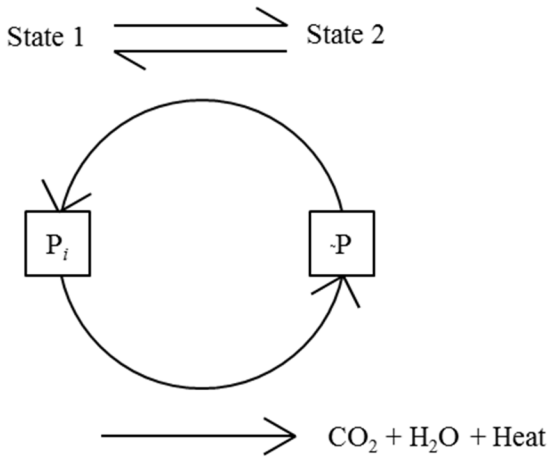

Figure 1.2 Relationship between high energy phosphate synthesis and substrate oxidation (Baldwin, 1995)

Energy partitioning in growing pigs

Current models for energy systems in animal production are based on the partitioning of energy intake into different outcomes (Ferrell, 2008). Characterization of these outcomes has been the subject of extensive study (Brody, 1945; Kleiber, 1947; Noblet, 1994; Baldwin, 1995; Whittemore, 1997; Van Milgen, 2003; de Lange and Birkett, 2005). Current partitioning models divide energy into two main components: energy losses (fecal energy, urinary energy, gaseous energy, energy released as heat, product formation energy) and energy retained (tissue accretion).

Energy released as heat includes energy required by reactions supporting physiological functions, such as digestion and absorption, basal metabolism, excretion, voluntary activity, thermoregulation and the immune response. It includes non-animal heat production, namely heat produced by microbial fermentation in the intestine. Quantifying energy released as heat is very difficult and variable because it depends on several factors such as genotype, metabolic state, environmental factors, physical activity, immune status, and the diet (Ferrell, 2008; Knap, 2009)

Maintenance energy

This concept establishes a baseline to quantify physiological energetic needs (Milgen, 2006). Although there are several definitions of maintenance, it can be described as energy intake adequate to support zero energy balance (Baldwin, 1995). However, because energy balance is difficult to measure, maintenance is often approximated to the energy intake in which animals maintain a constant body weight (Knap, 2009). Although this approximation implies no energy retention as protein or lipids, or energy loss, for growing pigs this scenario corresponds to

a non-physiological situation because immature animals tend to deposit protein at the expense of lipids when they are fed at maintenance (Baldwin, 1995; Van Milgen, 2003; Knap, 2009).

Baldwin (1995) divides maintenance in two components – the cost of digestion and assimilation plus fasting heat production. The first component is the heat produced after ingesting a meal and is associated with bond breakage, nutrient absorption, synthesis of digestive proteins, and assimilation or storage of nutrients. The second accounts for the heat produced under fasting conditions, including service and repair functions such as the work of the kidney and the heart, functions of the nervous system, respiration, protein turnover, triacylglycerol synthesis, and maintaining membrane potential (Na^+ transport). It is important to note that during fasting, pigs depend on glycogen, triglycerides, and protein body reserves to supply their energy needs.

Variations in heat production among pigs result from differences in health status, physiological state, and environment (Baldwin, 1995). Actions such as thermoregulation, immune response, and coping with other stressors are often excluded from "maintenance" and may be included as adjustments.

Energy for maintenance is a function of metabolic BW, which is BW raised to the power of 0.60 ($BW^{0.60}$) (Noblet et al., 1999; NRC, 2012). However, other studies have suggested that the exponent may range from 0.54 to 0.75 (Tess, 1981).

Definition and role of an energy system

Energy systems can be defined as the attribution of energy concentration to diets or ingredients based on energy utilization. Values for energy systems can be determined by measuring and discounting energy losses (Milgen, 2006) or they can be calculated using

prediction equations (Kil, 2013). In practice, since it is difficult and costly to directly measure the energy value of a diet through determining energy loses, equations to estimate energy values are used (Milgen, 2006). Prediction equations relate the energy value of a diet to its chemical composition assuming that the sources of the feedstuffs do not significantly affect prediction responses (Noblet and Perez, 1993). Additionally, energy values from individual ingredients are presumed to be additive (Emmans, 1994; de Lange and Birkett, 2005; Kil, 2013).

As outlined by Patience (2012), energy systems play two active roles in diet formulation and the development of feeding programs. First, they assign nutritional and economic values to feed ingredients; second, they support the formulation of diets that hopefully result in predictable performance outcomes. Therefore, the success of an energy system is based on its ability to best use available ingredients in the correct proportions to achieve predictable outcomes while minimizing the cost (Noblet, 1994; Whittemore, 1997; Moehn, 2005)

Energy systems

- Digestible energy system (DE)

Digestible energy is defined as gross energy present in the feed minus the energy excreted in feces. DE for swine often varies between 70 to 90% of the original dietary gross energy (van Milgen and Noblet, 1999). This means that DE accounts for a substantial proportion of the variability of dietary energy utilized by the pig. Digestible energy can be determined using the following methods (Adeola, 2000; Agudelo et al., 2010):

Total collection method:

Digestibility of gross energy, % = (((energy intake, kcal – energy in feces, kcal) / energy intake, kcal) ×100)

Indigestible marker method:

Digestibility of gross energy, % = (100 − (100 × (% marker in feed / % marker in feces) × (energy in feces, kcal/kg / energy in feed, kcal/kg)))

Although the determination of digestibility is robust, some factors such as passage rate, interactions among nutrients and ingredients, capacity for fermentation and health status may affect it. It is also important to note that endogenous loses are not usually considered.

Some equations to estimate digestible energy from dietary composition are i.e. (Noblet and Perez, 1993)

$$DE = 1{,}161 + (0.749 \times GE) - (4.3 \times Ash) - (4.1 * NDF)$$

$$DE = 4{,}168 - (9.1 \times Ash) + (1.9 \times CP) + (3.9 \times EE) - (3.9 \times NDF)$$

- Metabolizable energy system (ME)

Metabolizable energy is defined as digestible energy less that quantity of energy excreted in the urine and as fermentation gases.

Metabolizable energy values can be determined by measuring urinary energy in a bomb calorimeter (May, 1972); gaseous energy loses associated with fermentation - largely methane - are generally ignored (de Lange and Birkett, 2005). This may be due to an insignificant discount of DE (about 0.4%; Noblet and van Milgen, 2004). Another way to calculate energy lost in urine

is using the strong relationship between urinary nitrogen and urinary energy (Noblet and van Milgen, 2004):

$$\text{Urinary energy in pigs} = 192 + 31 \times \text{Urinary nitrogen}$$

Some of the issues determining metabolizable energy are the loss of nitrogen through volatilization, the inherent error of measuring the energy content of urine and the lack of a practical way to measure energy lost in gases.

Examples of equations for estimating the metabolizable energy content of diets are those proposed by Noblet et al. (1993):

$$ME = 4.194 - (9.2 \times Ash) + (1.0 \times CP) + (4.1 \times EE) - (3.5 \times NDF)$$

$$ME = (1.0 \times DE) - (0.68 \times CP)$$

- Net energy system (NE)

Net energy is defined as metabolizable energy minus the heat increment of feeding. Therefore, NE ultimately represents the energy available for maintenance and for tissue accretion (NE for production).

Estimation of NE is much more difficult than DE or ME. It requires measuring heat production or energy retention. Heat production assumes that all metabolizable energy that is not retained by the animal is lost as heat (Milgen, 2006). Therefore, it can be determined by estimating heat production under differing physiological stages (fasting vs fed state, etc.).

Heat production can be determined by measuring heat loss by different channels of conduction, radiation, convection, and evaporation or by measuring all three in a direct

calorimeter or combined with evaporation (Boisen and Verstegen, 2000). However, the most common method to measure heat production is by indirect calorimetry. Indirect calorimetry estimates heat production by measuring gas exchange and the excretion of urinary nitrogen in a respiratory chamber, according to the Brouwer equation (Brouwer, 1965; Rijnen et al., 2003; Milgen, 2006):

$$\text{Heat production, kcal} = (3.866 \times O_2 \text{ consumption, l}) + (1.200 \times CO_2 \text{ production, l}) - (0.518 \times CH_4 \text{ production, l}) - (1.431 \text{ N urine, production, g})$$

NE for maintenance cannot be determined directly by experimental means (Birkett and de Lange, 2001). Fasting heat production however, can be estimated as the asymptotic heat production after a period of food depravation of ≥24 h (van Milgen et al., 2001).

Retained energy (RE) can then be calculated discounting the metabolizable energy by the total heat production:

$$RE = ME - HP$$

Finally NE can be calculated by the sum of RE and FHP, and then dividing by dry matter intake (DMI).

$$NE = (RE + FHP)/ DMI$$

NE can be estimated from RE in a technique called “comparative slaughter”. This technique measures the energy gain by the pig related to the amount of feed ingested. Basically, a group of pigs is separated in two; the first group of pigs is killed, ground, dried and assayed for gross energy using a bomb calorimeter at the beginning of the feeding period, and is typically called the initial slaughter group. The second group is fed diets of known ME concentration for

a fixed period of time. At the end of the period, the second group is sacrificed and the carcass analyzed the same way as the first group. The RE is the difference in the carcass energy content between the first and second slaughter (Adeola, 2000).

As with the other energy systems, NE can be derived from the diet as a function of diet composition. Essentially, relationships between NE and diet nutrient composition are interpreted statistically and represented empirically (de Lange and Birkett, 2005).

The following are the equations listed in the NRC (2012) based on equations developed by Noblet et al. (1994):

$$NE = (0.726 \times ME) + (1.33 * EE) + (0.39 \times Starch) – (0.62 \times CP) – (0.83 \times ADF)$$

$$NE = (0.700 \times DE) + (1.61 * EE) + (0.48 \times Starch) – (0.91 \times CP) – (0.87 \times ADF)$$

$$NE = (2.73 \times DCP) + (8.37 \times DEE) + (3.44 \times Starch) + (2.89 \times DRES)$$

Where DRES = DOM – (DCP + DEE + Starch + DADF), DCP is digestible crude protein, DEE is digestible ether extract, and DADF is digestible acid detergent fiber. Nutrient contents are expressed as g/kg and energy values are in kcal/kg of DM.

The Dutch NE system

This system was developed by the Central Bureau Livestock Feeding (CVB) in the Netherlands using a variation of one of the NE prediction equations developed by the French (Stewart, 2007). This energy system divides total digestible carbohydrates into an enzymatically digestible fraction and a fermentable fraction owing to differences in energetic utilization of carbohydrates between the small and the large intestine of pigs (Velayudhan et al., 2015). NE can then be calculated using the following equation:

NE (kcal/kg) = (28.0× % digestible CP) + (85.4× % digestible EE after acid hydrolysis) + (33.8 × % starch-e) + (30.5 × % sugar-e) + (23.3×% FCH)

Energy and chemical components are expressed on a DM basis, starch-e is enzymatically digestible starch, sugar-e is enzymatically digestible sugar, FCH (fermentable carbohydrates) = fermentable starch (starch-f, zero value except for potato starch) + fermentable sugar (= total sugar – sugar-e) + digestible NSP; digestible NSP = digestible OM – digestible CP – digestible EE – starch-e – 0.95×total sugar.

The Danish system

The potential physiological energy (PPE) system was developed by Boisen and evaluates the feed ingredient based on the oxidation of nutrients used for synthesis of ATP. It employs *in vitro* digestibility methods to avoid the effects of animals in nutrient digestibility (Boisen and Verstegen, 1998; Velayudhan et al., 2015). Energy values for this energy system are expressed in Feed Units (FU) using the following equation:

FU growing pig, per kg DM = [9.9 × RDCP + 31.7 × RDCF + factor × IDC + 7.0 × FC - 28 × EUDMi]/7375

where RDCF is ileal digestible crude fat, IDC is ileal digestible carbohydrate, FC is fermentable carbohydrate and EUDMi is enzyme undigested ileal dry matter. All values are expressed in g/kg DM.

Comparison between ME and NE

Rather than being conceptually divergent, differences between the ME and the NE system are hierarchical. The NE system represents one step forward in estimating the actual

valuable energy for the pig, because it represents usable energy, while the ME system represents potential energy (Moehn, 2005). Ultimately, it is clear that energy transactions present in the various metabolic processes should be accounted for in order to gain accuracy in the estimation of energy requirements.

There are practical reasons why the NE system has not been more widely adopted in the U.S. First, the ME system has been extensively used and refined, which makes it easier and more comfortable to use. As a result, there has been some reluctance to implementing the NE system. Secondly, there is limited testing on the NE system under North American conditions, making its adoption less comfortable.

In any case, even if the ME system has worked historically, there is a cost associated with not advancing to adopt a better energy system.

Practical differences

The main practical difference between the ME and the NE system is a highly variable NE: ME ratio among feed ingredients. NE accounts for the metabolic efficiency with which different dietary compounds are used for maintenance and energy retention. Ingredients' differing profile of chemical components can be similar for ME, but different in their NE concentration. As a result, NE is more helpful than the ME system in ranking feed ingredients according to their supply of useful energy to the pig (Patience, 2012).

On the other hand, although the NE:ME ratio in diets is less variable than for feed ingredients, it is estimated that the ME system overestimates the energy value of high fiber and high protein diets, and underestimates the energy value of high starch and high fat diets (Noblet,

1994). This difference should result in better predictability of animal performance under the NE system.

Adopting the NE system

Since NE values should have the advantage of being more accurate in terms of usable energy than the ME system, the logical move is to adopt the NE system. However, there are at least two big challenges to overcome: first, to prove the level of precision of NE values in the North American context, and second, to improve the familiarity of the concepts and practice around the NE system (Patience, 2012).

Conclusions

In conclusion, current models for energy systems in animal production are based on the partitioning of energy intake into different components of energy utilization. Methodologies to estimate energy values are based on measuring energy loses (fecal energy, urinary energy, gaseous energy, energy released as heat, product formation energy and energy retention). Ultimately, energy systems attribute a determined energy concentration to diets or ingredients based in energy utilization. Prediction equations to estimate ingredient or dietary energy concentrations have been proposed in order to simplify the process of obtaining energy values. The ME system is widely used in North America; however, the NE system is gaining attention based on estimated usable energy. This advantage is reflected in a superior ability to rank feed ingredients according to their usable energy content, and thus potentially achieve better prediction of growth performance.

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CHAPTER II

COMPARISON OF THE GROWTH PERFORMANCE AND CALORIC EFFICIENCY OF GROWING PIGS OFFERED FEEDING PROGRAMS BASED ON THE ME OR THE NE SYSTEM

A paper submitted to the *Journal of Animal Science*

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Abstract

The net energy (NE) system describes the useful energy for growth better than the metabolizable energy (ME) system. This NE system should maintain growth performance and carcass parameters when diverse ingredients are used. However, this statement needs to be demonstrated in practice. This study compared the pig growth performance, carcass characteristics and caloric efficiency on diet programs formulated using either the ME or NE systems. A total of 944 gilts and 1,110 castrates (initial BW=40.8±2.0 kg) were allotted to separate pens and assigned to one of 5 different feeding programs. A simple corn-soybean meal control (Ctl) served as the basis to establish baseline levels of ME and NE concentrations. One set of two treatments added DDGS to the Ctl diet formulated using the ME or the NE system (ME-D and NE-D; respectively) and another set of diets that added both DDGS and corn germ meal and was formulated using the ME or the NE system (ME-DC and NE-DC; respectively). Addition of soybean oil varied to achieve either constant ME or NE levels as required.

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Pigs were harvested at a mean BW of 130.3±4.0 kg. Overall growth performance was not affected by treatment (*P*=0.581, *P*=0. 177 and *P*=0.187 for ADG, ADFI and G: F ratio respectively). However, carcass composition declined with the addition of co-products except for NE-D treatment (*P*=0.016, *P*=0.001, *P*=0.014, *P*=0.018, *P*=0.010 and *P*=0.010 for dressing percentage, hot carcass weight, carcass gain, carcass ADG, back fat and loin depth respectively). Carcass G: F and lean percentage did not differ among treatments (*P*=0.109 and *P*=0.433). NE intake decreased (*P*=0.035) in the same fashion that carcass gain did, suggesting a relationship between energy intake and energy retention. NE per kg of BW differed among treatments (*P*=0.010), but NE per kg of carcass was similar to the control (*P*=0.640), suggesting that NE is better at explaining the carcass results. ME intake and ME per kg of BW were not significantly different among treatments (*P*=0.112), but ME per kg of carcass gain was significantly different among treatments (*P*=0.048). In conclusion, formulating diets based on NE provided results at least as good as ME, and in some cases better following the sequential addition of co-product ingredients. This confirmed that growth rate or carcass parameters should not suffer with the adoption of the NE system.

Keywords: Carcass characteristics, growth performance, energy efficiency, energy intake, swine

Introduction

Feed is the largest single expense in swine production, with energy representing the greatest proportion of feed expense (Noblet, 1994; Stein and Shurson, 2009; Gutierrez and Patience, 2012). Energy systems quantify the concentration of energy in the diet and should account for the energy available to the pig for growth and maintenance. The purposes of energy

systems are to facilitate the blending of diverse ingredients into a diet with predictable performance outcomes and to serve as a basis for assigning relative economic values to ingredients that vary in energy content. Currently in the U.S., the ME and the modified ME systems are widely used, but the NE system is attracting more interest because of its theoretical potential to better estimate energy supplied to, and utilized by, the pig (Patience, 2012).

The NE system essentially discounts the metabolic cost of converting ME into useful forms of energy for supporting maintenance and production processes (Patience, 2012). These discounts are variable (89.1, 82.0, 55.9 and 59.2% for fat, starch, fiber and protein respectively) among dietary components (Noblet, 2005; Milgen, 2006). Thus useful energy can be overestimated or underestimated by the ME system (Noblet, 1994).

Alternative ingredient inclusion has become a common practice in swine diets in the U.S. as a strategy to lower the cost of feeding pigs. These ingredients generally bring increased amounts of fiber into the diet (Gutierrez et al., 2013), raising questions about the effectiveness of the ME system, which will tend to overestimate energy available from fiber.

The objectives of this study were *i*) to determine if animal growth performance and carcass characteristics are better reflected by ME or NE across diets of diverse composition, and *ii*) to determine if dietary ME or NE better predict the efficiency of dietary energy utilization across diets differing in alternative ingredient composition.

Materials and methods

The protocol for this experiment was approved by the Institutional Animal Care and Use Committee at Iowa State University (No. 6-12-7396-S).

Animals, Housing and Experimental Design

This experiment was conducted at The Hanor Company Research Facility, (White Hall, IL) in two barns equipped with a computerized feed delivery system (Big Dutchman, Inc, Holland, MI). A total of 2,054 crossbred pigs (1,110 barrows and 944 gilts, the progeny of PIC Camborough sows × TR4 sires [PIC, Hendersonville, TN] and with an initial BW of 40.8±0.5 kg) were assigned on the basis of BW and sex into 19 blocks (10 blocks for barrows and 9 blocks for gilts) and randomly assigned to 1 of 5 dietary treatments. Pigs were allotted to 95 pens (19 to 24 pigs per pen). Each pen had a completely slatted concrete floor and was equipped with a 4-space stainless steel dry feeder and two nipple drinkers providing *ad libitum* access to feed and water. At the end of the experiment, pigs were shipped in 4 cuts to Triumph Foods (St Joseph, MO) where carcass data were collected. In each cut, a similar number of pigs in each pen was sent in order to have consistent measurements for each treatment (28, 30, 34 and 8% of the total pigs were sent from cuts 1 through 4, respectively).

Dietary Treatments

Diets were delivered as a mash in 3 phases: (41-61, 61-83 and 83-130 kg BW for phase 1 to 3 respectively). Barrows and gilts received the same diets but switched dietary phases within gender, based on BW and previously determined Lys requirements for pigs in this herd. The 5 dietary treatments (Tables 2 to 4) included a simple corn-soybean meal control diet (Ctl) that served as the basis to establish the ME and NE concentrations for the other dietary treatments. The next two treatments (ME-D and NE-D) included corn DDGS (>10% oil; 25% inclusion in

phase 1 and 30% in phases 2 and 3) and were formulated either to an equal ME or to an equal NE concentration compared with the Ctl. The second set of two dietary treatments (ME-DC and NE-DC) contained both corn DDGS (15% inclusion for phase 1 and 20% for phase 2 and 3) and corn germ meal (20% for all dietary phases) and were also formulated to either constant ME or NE content relative to the Ctl. Choice white grease was added to the diets as required to meet the energy formulation guidelines. All experimental diets were formulated to meet or exceed the nutrient requirements for pigs from 40 to 130 kg (NRC, 2012). Standardized ileal digestibility (SID) of lysine, minimum ratios of essential amino acids to lysine and available phosphorous were held constant across all experimental diets within each phase.

Chemical Analysis and Calculations

Prior to formulating the diets, corn, soybean meal, corn DDGS and corn germ meal samples were finely ground and DM (Method 930.15; AOAC, 2007), ash (Method 942.05, AOAC, 1942), ADF and NDF (Van Soest and Robertson, 1979), crude protein as nitrogen × 6.25 (Method 984.13 A-D, AOAC, 2006) and ether extract (EE; method 920.39, AOAC, 2005) were assayed at the Agricultural Experiment Station Chemical Laboratories (University of Missouri-Columbia, MO). Starch content was determined on all ingredient samples (Modified method 996.11, AOAC 1996) at the Monogastric Nutrition Laboratory (Iowa State University, Ames, IA). Values provided from these assays as well as the ME values published in the NRC, 2012, were used to estimate NE according to equation [1-7] published in NRC (2012):

$$NE = (0.726 \times ME) + (1.33 \times EE) + (0.39 \times Starch) - (0.62 \times CP) - (0.83 \times ADF)$$

where energy is expressed in kcal/kg and dietary constituents in g/kg.

Growth performance parameters were calculated by measuring BW and feed disappearance, computed on a pen basis and divided by pig days in order to calculate ADG and ADFI, while G:F ratio was calculated by dividing total growth by total feed intake.

Dressing percentage was calculated as the hot carcass weight divided by the market BW times 100. Loin depth and back fat thickness were measured using a fat-o-meter system (FOM, FK Technology Fat-O-Meter, Herley, Denmark), with measurements taken between the 3-4th last rib. Percent lean was calculated using the packing plant's own proprietary equation. Carcass gain was calculated by subtracting hot carcass weight from the initial carcass weight, which was estimated as the initial BW × 0.74. The dressing percentage at the start of the experiment was assumed to be similar to the final dressing percentage, which based on the literature should be approximately correct (Oresanya et al., 2008).

ME and NE intake (Mcal /d) were calculated from the estimated ME and calculated NE dietary concentration × ADFI (both on an as-fed basis). Dietary energy efficiency was determined as ME or NE per kg of BW gain, and was calculated by dividing ME intake or NE intake by ADG. Carcass basis energy efficiency was determined as ME or NE per kg of carcass gain and was calculated by dividing ME or NE intake by carcass ADG.

The estimated ME and NE available for growth were calculated using the following equations:

$$\text{ME for growth} = ME_I - ME_m$$

$$\text{NE for growth} = NE_I - NE_m$$

where ME_I and NE_I are ME and NE intakes in Mcal/d, respectively, and ME_m and NE_m were calculated using NRC (2012) and van Milgen et al. (2008) equations respectively:

$$ME_m = 197 \times BW^{0.60}$$

$$NE_m \text{ (kj/d)} = (FHP \times 0.708 + 207) \times (BW, \text{ kg})^{0.60}$$

NE_m was converted to calories using 0.239 as a conversion factor; FHP is fasting heat production calculated accounting for the level of feed intake using the following equation (van Milgen et al., 2008):

$$\text{FHP, kJ.kg of BW}(-0.60).\text{d}(-1) = 436 + 175 \times (\text{NE intake, MJ/d}) / (\text{kg BW})^{0.60}$$

Once calculated, mean BW was calculated for each pen as the initial BW + (slope of all BW) × (the median days on treatment, 47d).

Statistical Analysis

The UNIVARIATE procedure of SAS (SAS Inst., Inc., Cary, NC) was used to analyze normality and extreme observations. The MIXED procedure of SAS was applied, including treatment and sex as fixed effects and block as a random effect in the model. Interactions between sex and treatment were tested and eliminated from the model when they were not a significant source of variation ($P \leq 0.05$). Differences among treatments were considered statistically significant with $P \leq 0.05$ and trends from $P > 0.05$ to $P \leq 0.10$. Least square mean differences among treatments were determined using the protected LSD test. Pen was the experimental unit in all analyses.

Results

Chemical analysis, NE and ME from ingredients

Dry matter, crude protein (N × 6.25), ether extract, starch, ADF and NDF, as well as the calculated NE values for the four main ingredients (Table 1; corn, soybean meal, corn DDGS and corn germ meal) were in close agreement with the values published by the NRC (2012). The calculated values for the NE content of each ingredient, based on actual chemical assays, did not deviate more than 2% from the values published by the NRC (2012).

Growth performance

From d 0 to 21, pig BW was not different among treatments (Table 5; P >0.10). At d 42, pigs fed ME-D, ME-DC and NE-DC were lighter than pigs fed the Ctl diet ($P < 0.05$), but pigs fed NE-D had a BW similar to those fed the control diet. Pigs fed NE-DC were lighter than the pigs fed the Ctl or the NE-D diets ($P < 0.05$). At d 63, pigs fed ME-D, ME-DC and NE-DC were lighter than pigs fed the Ctl diet ($P < 0.05$), but pigs fed NE-D had a BW similar to those fed the control diet (P > 0.10). From d 84 to market, there were no significant differences in BW among treatments ($P > 0.05$).

In the first growth phase, pigs fed ME-D, NE-D and ME-DC diets maintained the same ADG as the pigs on the Ctl diet (Table 6). Only pigs fed the NE-DC diet gained less than pigs fed the Ctl diet ($P < 0.05$). ADFI was lower in pigs fed ME-DC and NE-DC diets than pigs fed the Ctl diet ($P < 0.05$). Pigs fed the ME-DC showed a greater G:F ratio than those fed the Ctl diet ($P < 0.05$). Pigs fed ME-DC or NE-DC had a better feed efficiency than pigs fed the NE-D diet.

In the second growth phase, pigs fed ME-D, ME-DC and NE-DC diets had lower ADG compared to pigs fed the Ctl diet ($P < 0.05$). In contrast, pigs fed the NE-D diet maintained an ADG similar to that of pigs on the Ctl diet. Pigs fed ME-DC and NE-DC diets ate less feed than those on the Ctl diet ($P < 0.05$) while pigs fed ME-D or NE-D were similar to the control diet. G: F ratio was not significantly different among dietary treatments ($P > 0.10$).

In the third growth phase, as well as for the overall experiment, ADG, ADFI and G:F ratio were not different among treatments ($P > 0.10$). There were no interactions between sex and treatment for any growth performance variable ($P > 0.10$).

Carcass data

Pigs fed the ME-D, ME-DC and NE-DC diets had lower HCW and dressing percentage compared with those fed the Ctl diet (Table 7; $P < 0.05$). However, pigs fed the NE-D diet maintained a similar HCW and dressing percentage as those on the Ctl diet ($P > 0.05$). Total carcass gain was lower in pigs fed with ME-D, ME-DC and NE-DC diets compared with those fed the Ctl or the NE-D diets ($P < 0.05$). Carcass ADG was lower in pigs fed the ME-D, ME-DC and NE-DC diets compared with those fed the Ctl diet ($P < 0.05$). Carcass gain of the pigs fed the NE-D diet was similar to that of pigs fed the Ctl diet ($P > 0.10$). Carcass G:F ratio was not different among treatments ($P > 0.10$).

Back fat was similar in pigs on the NE-D and the Ctl diets ($P < 0.05$); however, it was lower for pigs fed ME-D, ME-DC and NE-DC compared with those on the Ctl diet ($P < 0.05$). Loin depth was similar in pigs fed ME-D and NE-D and the Ctl diet ($P > 0.10$), but pigs fed ME-DC and NE-DC diets had smaller loins compared with those fed the Ctl diet ($P < 0.05$). There were no differences in FOM lean percentage among all treatments. There were no interactions between sex and treatment for any carcass parameter ($P > 0.10$).

Energy intake and efficiency

In the first growth phase, daily intake of ME or NE was lower in pigs fed the ME-DC and NE-DC diets than those fed the Ctl diet ($P < 0.05$). Pigs fed these diets needed less energy (ME or NE) per kg of BW than those fed the Ctl diet ($P < 0.05$). In contrast, pigs on the ME-D and NE-D diets consumed the same quantity of ME or NE as the pigs fed the Ctl diet and used the same amount of ME or NE per kg of BW gain ($P > 0.10$).

In the second phase, average daily NE intake was lower in pigs fed ME-DC and NE-DC diets than those fed the Ctl diet ($P < 0.05$), while pigs on ME-D and NE-D diets maintained a

similar NE intake compared with those fed the Ctl diet ($P > 0.05$). NE per kg of BW was not significantly different among treatments ($P > 0.10$). Average daily ME intake tended to be lower in pigs fed ME-DC than those fed the Ctl diet ($P < 0.10$), while pigs fed NE-DC, ME-D and NE-D had similar average daily ME intake compared with those fed the Ctl diet ($P > 0.10$). ME per kg of BW was greater in pigs fed ME-D and NE-D diets than those fed the Ctl diet ($P < 0.05$), while pigs on ME-DC and NE-DC diets were similar in terms of ME per kg of BW compared with the Ctl diet ($P > 0.05$).

In the third phase there were no significant differences among treatments for average daily energy intake or for efficiency of energy utilization ($P > 0.10$).

For the overall period, average daily NE intake was lower in pigs fed ME-DC compared with those fed the Ctl diet ($P < 0.05$), while pigs fed ME-D, NE-D and NE-DC ate the same quantity of NE compared with those fed the Ctl diet ($P > 0.05$). Calculated NE_m was not significantly different among treatments. In contrast, calculated NE available for growth was lower for pigs fed ME-DC and NE-DC treatments compared with those fed the Ctl diet ($P < 0.05$), while those fed ME-D and NE-D had similar NE available for growth as those fed the Ctl diet.

NE per kg of BW was lower on the ME-D, ME-DC and NE-DC treatments compared with those fed the Ctl diet ($P < 0.05$), while those fed NE-D utilized the same quantity of NE per kg of BW as those fed the Ctl diet. NE consumed per kg of carcass weight was not significantly different among treatments ($P > 0.10$). Average daily ME intake, ME_m and ME consumed per kg of BW were not significantly different among treatments ($P > 0.10$). Although ME for growth was not different between pigs fed the Ctl diets than the rest of the treatments ($P > 0.05$), it was higher for pigs fed NE-D compared with those fed ME-DC and NE-DC diets ($P < 0.05$).

ME intake per kg of carcass was higher in pigs fed ME-D and NE-D than in those fed the Ctl diet ($P < 0.05$), while pigs fed ME-DC and NE-D needed a similar quantity of ME consumed per kg of BW compared with those fed the Ctl diet ($P > 0.05$). There were no interactions between sex and treatment for any energy intake and efficiency variables ($P > 0.10$).

Discussion

A feeding program is effective when a change in ingredient composition has no unexpected effect on animal growth performance (Blaxter and Boyne, 1978; Ferrell, 2008; Beaulieu et al., 2009). In order to achieve this predictable outcome, quantifying the energy content of ingredients and of the mixed feed is essential. As reported herein, the values from the assay of the ingredients not only supported the calculation of NE concentrations, but also confirmed strong agreement between published values (NRC, 2012) for the ingredients and diets and the values calculated using the Noblet, 1994 equation.

Results from the first two dietary phases indicated a reduced ADFI in pigs fed isocaloric (ME or NE) diets containing both corn DDGS and corn germ meal. Although no detrimental effects on growth performance have been reported feeding up to 30% corn DDGS (Stein and Shurson, 2009; Stein, 2011; Weber et al., 2015), and 38% corn germ meal (Weber et al., 2010), lower initial feed intake can occur on higher fiber diets (Weber et al., 2010; Jha et al., 2013). This effect is mainly attributed to limited gut capacity in the pig (Bach Knudsen and Hansen, 1991; Kyriazakis and Emmans, 1995; Nyachoti et al., 2004; Gutierrez et al., 2013; Zhang et al., 2013). In any event, maintaining NE or ME concentration at the same level of a corn-soybean meal diet cannot result in equal performance if feed intake is compromised.

Despite the reduction in feed intake being a big limitation for energy systems to result in equal growth performance comparing simple and complex diets, this may be a temporary problem; heavier pigs have more gastrointestinal capacity, facilitating a greater volume of feed intake and therefore a more successful adaptation to higher fiber diets (Kyriazakis and Emmans, 1995; Gutierrez et al., 2013). This effect was confirmed in the last phase of this experiment, where feed intake of pigs fed the high fiber diets was similar to pigs fed the corn-soy diet.

When growth performance is summarized over the three dietary phases (0 to 94d), results suggest that a corn-soybean meal diet - basically a diet higher in starch and lower in fat and fiber - can be replaced with diets containing co-products (lower in starch and higher in fiber content). With comparable overall growth performance observed across all diets in this study, it is reasonable to conclude that the ME and NE values and the overall formulations of the diets were quite accurate.

Similar growth performance between high co-product ME diets and their NE counterparts may be the result of very similar NE:ME ratios among diets. Despite adding up to 40% of co-product ingredients into the diet, the NE:ME ratio remained fairly constant (0.73-0.75) among the 5 dietary treatments. This occurred in spite of the fact that the NE:ME ratio between corn and high fiber co-product ingredients is large, and that the inclusion of these ingredients would normally result in a lower NE:ME ratio (Noblet, 1994). The addition of choice white grease kept the ratios quite similar. In fact, the main difference between the NE and the ME diets was the quantity of the added fat, which was greater when formulated with the NE system than the ME system. This difference is the result of the greater discount given to fiber in the NE as compared to the ME system (Noblet, 1994; Soenke Moehn, 2005). Since the NE:ME ratios were narrow,

the pressure placed on the two systems was not greater than one would see in commercial practice.

Carcass results showed that NE formulations were effective with the addition of corn DDGS, but were less effective when both corn DDGS and corn germ were included. In contrast, formulations under the ME system were not successful in maintaining a constant dressing percentage. Inconsistent dressing percentage data have been reported in pigs fed different levels of corn DDGS (NRC, 2012). Widmer et al. (2008) and Xu et al. (2008) reported no effect of fibrous ingredients on dressing percentage while Cook et al. (2005), Whitney et al. (2006), Linneen et al. (2008) and Weber et al. (2015) observed a lower dressing percentage. A lower dressing percentage in pigs fed high fiber diets is usually related to hypertrophic effects on the gastrointestinal tract (Anugwa et al., 1989; Pond et al., 1989; Kerr and Shurson, 2013). However, little to no attention has been given to the energy supply, typically low when highly fibrous ingredients are included. Results of this experiment suggest that at least partially (only with the inclusion of DDGS), equal dressing percentages can be the achieved with the NE system.

Energy intake and efficiency of energy utilization are alternative options for evaluating growth performance and carcass characteristics. These parameters have at least two important advantages compared to the traditional growth and carcass performance evaluation. First, energy intake and efficiency of energy utilization describe the feed supply in terms of energy rather than weight (Patience, 2012). Second, they allow for evaluation of all diets in terms of NE or ME, regardless of the energy system used in the formulation, facilitating NE and ME comparison from a different perspective. For each dietary phase, NE and ME intake and efficiency were consistent with the whole BW performance results, except for phase 2, where ME per kg of BW was higher for diets including DDGS compared with the Ctl diet.

Energy intake and the efficiency of energy utilization over the total length of the study were perhaps the most relevant variables for evaluation of the differences between the ME and the NE systems. The idea of using an energy system in this manner is to describe accurately energy utilization, so energy intake should explain energy retention. Additionally, similar amounts of energy are expected to increased BW or carcass size. Results on the diets based on the NE system suggest that different energy intakes especially are most likely to occur on the most complex diets. Calculated NE for growth confirmed that when NE is partitioned between maintenance and growth, there is less energy available for retention in these most complex diets; it also confirmed that with NE, maintenance is similar among treatments.

Although the NE system detected different energy efficiencies at the whole BW level, this variable could be influenced by additional weight of the intestinal contents. High fiber diets can add up to 38% more weight to viscera (Lorschy et al., 1997; de Lange et al., 2003); ultimately overestimating the energy efficiency of high fiber diets. NE efficiency was similar among diets at the carcass level; therefore the possibility of BW being influenced by greater intestinal contents in pigs fed high fiber diets seems to be reasonable.

On the other hand, the ME system provided contradictory results. Although ME intake was not significantly different among treatments, the quantity of ME available for growth was different among treatments. This may suggest that ME is less sensitive than the NE system in detecting differences in energy intake, which is fundamental in explaining energy retention. Although ME efficiency at the whole BW level was similar among treatments, ME efficiencies for carcass gain were different. Since ME is suggesting similar intakes, similar carcass gain also would have be expected.

In conclusion, the sequential addition of co-products in diets formulated on an NE or ME basis can result in similar growth performance. However, the addition of co-product ingredients, especially high fiber ingredients, can affect carcass characteristics independently of the energy system used. In this instance, diets formulated using the NE system seemed to be more robust than those formulated using the ME system when carcass parameters are concerned. Finally, calculations of caloric efficiency indicated that the NE system was better at predicting retained energy at the carcass level than the ME system in high fiber diets. Therefore, the NE system is better able to detect lower intakes in high fiber diets than the ME system. Overall, we can also conclude that in no instance was the ME system superior to the NE system.

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Table 2.1 Analyzed ingredient composition and calculation of NE for the ingredients utilized in the experimental diets (as-fed basis).

Ingredient	Corn	Corn germ meal	Corn DDGS	Soybean meal
Composition, %				
DM	86.70	89.16	89.70	89.70
CP	7.82	23.79	28.26	47.21
AEE	2.65	1.90	10.45	0.66
Starch	61.72	20.52	3.15	1.53
ADF	2.30	12.17	11.46	4.70
NDF	12.04	49.94	37.46	7.16
NE, Mcal/kg				
Calculated[1]	2.67	1.91	2.35	2.07
NRC, 2012 table	2.67	1.89	2.38	2.09

[1] From NRC 2012, equation [1-7]

Table 2.2 Ingredient inclusion and chemical and nutritional characteristic of phase 1 diets (as-fed basis[1]).

Item	Ctl[2]	ME-D[3]	NE-D[4]	ME-DC[5]	NE-DC[6]
Ingredient, %					
Corn	59.50	47.67	47.22	37.02	36.77
Soybean meal	35.20	22.00	22.00	20.00	20.00
Choice white grease	3.00	2.75	3.20	5.20	5.45
Corn DDGS, >10% oil		25.00	25.00	15.00	15.00
Corn germ meal				20.00	20.00
Limestone ground	0.89	1.25	1.24	1.17	1.17
Monocalcium phosphate	0.71	0.18	0.18	0.41	0.41
Salt	0.43	0.43	0.43	0.43	0.43
Vitamin premix	0.10	0.10	0.10	0.10	0.10
L-Lysine	0.10	0.40	0.40	0.41	0.41
DL-Methionine	0.05			0.02	0.02
L-Threonine	0.02	0.04	0.04	0.05	0.05
L-Tryptophan		0.04	0.04	0.04	0.04
Choline 60 dry	0.02	0.02	0.02	0.02	0.02
Iron oxide red		0.15		0.15	
Iron oxide black			0.15		0.15
Diet composition					
ME Mcal/Kg	3.43	3.45	3.47	3.44	3.47
NE Mcal/kg	2.54	2.53	2.55	2.53	2.54

Table 2.2 continued

NE:ME ratio	0.74	0.73	0.74	0.73	0.74
Starch, %	37.26	30.55	30.27	27.73	27.58
NDF, %	9.68	16.68	16.62	21.49	21.47
ADF, %	3.02	5.00	4.98	5.94	5.94
Ether extract, %	4.81	6.76	7.20	8.26	8.50
Crude protein, %	21.27	21.19	21.14	21.33	21.31
Lysine, %	1.27	1.29	1.29	1.32	1.32
SID Lys	1.15	1.15	1.15	1.15	1.15
SID AA: Lys ratio					
Thr	0.62	0.61	0.61	0.61	0.62
Trp	0.21	0.19	0.19	0.19	0.19
Met+ Cys	0.57	0.61	0.61	0.58	0.58
Calcium, %	0.68	0.68	0.68	0.68	0.68
Total phosphorous, %	0.61	0.55	0.55	0.57	0.57
STTD phosphorous, %	0.29	0.29	0.29	0.29	0.29

[1]Dietary treatments delivered in meal form from 0-21d

[2]Corn-soy based diet

[3]Control plus 25% of corn DDGS, ME equal to the corn-soy diet

[4]Control plus 25% of corn DDGS, NE equal to the corn-soy diet

[5] Control plus 25% of corn DDGS and 15% of corn germ meal, ME equal to the corn-soy diet

[6]Control plus 25% each of corn DDGS and 15% of corn germ meal, NE equal to the corn-soy diet

Table 2.3 Ingredient inclusion and chemical and nutritional characteristic of phase 2 diets (as-fed basis[1]).

Item	Ctl[2]	ME-D[3]	NE-D[4]	ME-DC[5]	NE-DC[6]
Ingredient, %					
Corn	63.78	49.34	48.69	38.39	37.94
Soybean meal	31.05	15.5	15.55	13.8	13.85
Choice white grease	3.00	2.65	3.25	5.15	5.55
Corn DDGS, >10% oil		30.00	30.00	20.00	20.00
Corn germ meal				20.00	20.00
Limestone ground	0.90	1.30	1.30	1.30	1.30
Monocalcium phosphate	0.73	0.10	0.10	0.32	0.32
Salt	0.40	0.40	0.40	0.40	0.40
Vitamin premix	0.10	0.10	0.10	0.10	0.10
L-Lysine		0.35	0.35	0.35	0.35
L-Threonine		0.02	0.02	0.02	0.02
L-Tryptophan		0.03	0.03	0.03	0.03
Iron oxide red		0.15		0.15	
Iron oxide black			0.15		0.15
Diet composition					
ME Mcal/Kg	3.43	3.45	3.48	3.45	3.47
NE Mcal/kg	2.56	2.55	2.57	2.55	2.56
NE:ME ratio	0.75	0.74	0.74	0.74	0.74
Starch, %	39.84	31.64	31.24	28.64	28.36

Table 2.3 continued

NDF, %	9.90	18.29	18.21	23.09	23.04
ADF, %	2.93	5.30	5.29	6.26	6.25
Ether extract, %	4.89	7.19	7.78	8.72	9.11
Crude protein, %	19.65	19.65	19.63	19.92	19.91
Lysine, %	1.08	1.11	1.11	1.14	1.14
SID Lys	0.97	0.97	0.97	0.97	0.97
SID AA: Lys ratio					
Thr	0.67	0.65	0.65	0.64	0.64
Trp	0.22	0.19	0.19	0.20	0.20
Met+ Cys	0.59	0.71	0.71	0.66	0.66
Calcium, %	0.68	0.68	0.68	0.68	0.68
Total phosphorous, %	0.59	0.53	0.52	0.55	0.55
STTD phosphorous, %	0.29	0.29	0.29	0.29	0.29

[1]Dietary treatments delivered in meal form from 21-42d

[2]Corn-soy based diet

[3]Control plus 30% of corn DDGS, ME equal to the corn-soy diet

[4]Control plus 30% of corn DDGS, NE equal to the corn-soy diet

[5]Control plus 20% of corn DDGS and 20% of corn germ meal, ME equal to the corn-soy diet

[6]Control plus 20% each of corn DDGS and 20% of corn germ meal, NE equal to the corn-soy diet

Table 2.4 Ingredient inclusion and chemical and nutritional characteristic of phase 3 diets (as-fed basis[1]).

Item	Ctl[1]	ME-D[2]	NE-D[3]	ME-DC[4]	NE-DC[5]
Ingredient, %					
Corn	70.11	51.05	49.75	40.88	39.98
Soybean meal	25.30	14.55	14.75	12.05	12.15
Choice white grease	2.50	2.20	3.30	4.70	5.50
Corn DDGS, >10% oil		30.00	30.00	20.00	20.00
Corn germ meal				20.00	20.00
Limestone ground	0.90	1.30	1.30	1.20	1.20
Monocalcium phosphate	0.68			0.25	0.25
Salt	0.40	0.40	0.40	0.40	0.40
Vitamin premix	0.10	0.10	0.10	0.10	0.10
L-Lysine		0.23	0.23	0.23	0.23
L-Tryptophan		0.02	0.02	0.02	0.02
Iron oxide red		0.15		0.15	
Iron oxide black			0.15		0.15
Diet composition					
ME Mcal/Kg	3.42	3.43	3.48	3.43	3.47
NE Mcal/kg	2.58	2.54	2.58	2.54	2.57
NE:ME ratio	0.75	0.74	0.74	0.74	0.74
Starch, %	43.66	32.68	31.88	30.15	29.59
NDF, %	10.25	18.43	18.28	23.26	23.16

Table 2.4 continued

ADF, %	2.80	5.30	5.28	6.23	6.22
Ether extract, %	4.52	6.78	7.85	8.33	9.10
Crude protein, %	17.42	19.34	19.33	19.29	19.27
Lysine, %	0.93	0.98	0.98	0.99	0.99
SID Lys	0.83	0.85	0.85	0.83	0.83
SID AA: Lys ratio					
Thr	0.69	0.71	0.71	0.70	0.70
Trp	0.22	0.20	0.20	0.20	0.20
Met+ Cys	0.63	0.80	0.79	0.76	0.75
Calcium, %	0.64	0.64	0.64	0.64	0.64
Total phosphorous, %	0.56	0.50	0.50	0.53	0.53
STTD phosphorous, %	0.27	0.27	0.27	0.27	0.27

[1]Dietary treatments delivered in meal form from 42-94d

[2]Corn-soy based diet

[3]Control plus 30% of corn DDGS, ME equal to the corn-soy diet

[4]Control plus 30% of corn DDGS, NE equal to the corn-soy diet

[5]Control plus 20% of corn DDGS and 20% of corn germ meal, ME equal to the corn-soy diet

[6]Control plus 20% each of corn DDGS and 20% of corn germ meal, NE equal to the corn-soy diet

Table 2.5 Impact of feeding in diets formulated using the ME or the NE systems on BW of growing pigs[1] (kg)

Day	Ctl[2]	ME-D[3]	NE-D[4]	ME-DC[5]	NE-DC[6]	SEM	*P*-value
0	41.0	41.0	41.0	41.0	41.0	0.7	1.000
21	61.4	61.0	61.2	61.1	60.4	0.7	0.134
42	83.9[a]	82.9[bc]	83.3[ab]	82.6[bc]	82.2[c]	0.8	0.008
63	104.3[a]	103.1[b]	104.5[a]	102.9[b]	103.2[b]	0.9	0.052
84	123.5	122.3	123.7	121.6	122.2	1.0	0.135
94 (Market BW)	131.2	130.5	131.6	129.8	130.5	1.1	0.555

[1]Data are least mean squares (2,054 pigs in 95pens), analyzed using the Mixed procedure of SAS®

[a-c] Within a row, least mean squares without a common superscript letter differ ($P \leq 0.05$).

[2]Corn-soy based diet

[3]Control plus 30% of corn DDGS (25% for phase 1), ME equal to the corn-soy diet

[4]Control plus 30% of corn DDGS, (25% for phase 1) NE equal to the corn-soy diet

[5]Control plus 20% each of corn DDGS and corn germ meal, (25 and 15% respectively for phase 1), and ME equal to the corn-soy diet

[6]Control plus 20% each of corn DDGS and corn germ meal, (25 and 15% respectively for phase 1), and NE equal to the corn-soy diet

Table 2.6 Whole body growth performance of pigs fed diets containing varying levels of co-product ingredients and formulated using the ME or the NE system[1].

Item	Ctl[2]	ME-D[3]	NE-D[4]	ME-DC[5]	NE-DC[6]	SEM	*P*-value
Phase 1, (0-21d)							
ADG, kg	0.968[a]	0.953[ab]	0.963[a]	0.956[ab]	0.924[b]	0.012	0.084
ADFI, kg	2.208[a]	2.179[a]	2.207[a]	2.114[b]	2.059[b]	0.025	<0.001
G:F ratio	0.438[ab]	0.437[ab]	0.436[a]	0.453[c]	0.450[bc]	0.006	0.026
Phase 2, (21-42d)							
ADG, kg	1.073[a]	1.040[b]	1.049[ab]	1.024[b]	1.037[b]	0.010	0.004
ADFI, kg	2.747[a]	2.697[ab]	2.722[ab]	2.645[b]	2.654[b]	0.031	0.072
G:F ratio	0.391	0.387	0.386	0.389	0.391	0.004	0.786
Phase 3, (42-94d)							
ADG, kg	0.966	0.984	0.976	0.964	0.974	0.016	0.895
ADFI, kg	2.991	2.990	2.998	2.940	2.961	0.041	0.797
G:F ratio	0.323	0.330	0.326	0.329	0.329	0.004	0.713
Overall (0-94d)							
ADG, kg	0.955	0.953	0.963	0.945	0.946	0.009	0.581
ADFI, kg	2.760	2.742	2.758	2.688	2.688	0.031	0.177
G:F ratio	0.346	0.349	0.350	0.352	0.353	0.002	0.187

[1]Data are least mean squares (2,054 pigs in 95pens), analyzed using the Mixed procedure of SAS®

[a-c] Within a row, least mean squares without a common superscript letter differ ($P \leq 0.05$)

[2]Corn-soy based diet

[3]Control plus 30% of corn DDGS (25% for phase 1), ME equal to the corn-soy diet

[4]Control plus 30% of corn DDGS, (25% for phase 1) NE equal to the corn-soy diet

[5]Control plus 20% each of corn DDGS and corn germ meal, (25 and 15% respectively for phase 1), and ME equal to the corn-soy diet

[6]Control plus 20% each of corn DDGS and corn germ meal, (25 and 15% respectively for phase 1), and NE equal to the corn-soy diet

Table 2.7 Carcass characteristics of pigs fed diets containing varying levels of co-product ingredients and formulated using the ME or the NE system[1].

Item	Ctl[2]	ME-D[3]	NE-D[4]	ME-DC[5]	NE-DC[6]	SEM	*P*-value
HCW, kg	97.0[a]	95.3[bc]	96.7[ab]	94.6[c]	95.3[bc]	0.8	0.016
Dressing, %	74.0[a]	73.1[bc]	73.6[ab]	72.8[c]	73.1[bc]	0.2	0.001
Carcass gain, kg	66.7[a]	65.0[b]	66.3[a]	64.2[b]	65.0[b]	0.6	0.014
Carcass ADG, kg/d	0.712[a]	0.694[bc]	0.708[ab]	0.686[c]	0.694[bc]	0.007	0.018
Carcass G:F ratio	0.258	0.254	0.257	0.256	0.259	0.001	0.109
FOM back fat, mm	21.7[a]	20.6[b]	21.3[ab]	20.9[b]	20.7[b]	0.4	0.010
FOM loin depth, mm	60.2[a]	59.3[abc]	59.6[ab]	58.4[c]	58.6[bc]	0.4	0.010
FOM lean, %	51.8	52.1	51.8	51.9	51.9	0.1	0.433

[1]Data are least mean squares (2,054 pigs in 95pens), analyzed using the Mixed procedure of SAS®

[a-c] Within a row, least mean squares without a common superscript letter differ ($P \leq 0.05$)

[2]Corn-soy based diet

[3]Control plus 30% of corn DDGS (25% for phase 1), ME equal to the corn-soy diet

[4]Control plus 30% of corn DDGS, (25% for phase 1) NE equal to the corn-soy diet

[5]Control plus 20% each of corn DDGS and corn germ meal, (25 and 15% respectively for phase 1), and ME equal to the corn-soy diet

[6]Control plus 20% each of corn DDGS and corn germ meal, (25 and 15% respectively for phase 1), and NE equal to the corn-soy diet

Table 2.8 Energy intake and efficiency of pigs fed diets containing varying levels of co-product ingredients and formulated using the ME or the NE system (as-fed basis) [1].

Item	Ctl[2]	ME-D[3]	NE-D[4]	ME-DC[5]	NE-DC[6]	SEM	*P*-value
Phase 1, Mcal/d							
NE intake	5.61[a]	5.52[a]	5.63[a]	5.35[b]	5.23[b]	0.06	<0.001
NE per kg of BW	5.79[a]	5.74[ab]	5.85[a]	5.59[c]	5.61[bc]	0.05	0.001
ME intake	7.57[a]	7.51[a]	7.65[a]	7.28[b]	7.11[b]	0.09	<0.001
ME per kg of BW	7.81[ab]	7.81[ab]	7.95[a]	7.61[c]	7.63[bc]	0.07	0.003
Phase 2, Mcal/d							
NE intake	7.04[a]	6.87[abc]	7.01[ab]	6.74[c]	6.80[bc]	0.08	0.020
NE per kg of BW	6.50	6.60	6.67	6.56	6.55	0.05	0.197
ME intake	9.50[a]	9.34[ab]	9.50[a]	9.15[b]	9.23[ab]	0.11	0.082
ME per kg of BW	8.70[b]	8.93[a]	9.02[a]	8.89[ab]	8.86[ab]	0.07	0.039
Phase 3, Mcal/d							
NE intake	7.71	7.58	7.75	7.46	7.62	0.11	0.279
NE per kg of BW	8.02	7.73	7.96	7.75	7.84	0.10	0.158
ME intake	10.22	10.26	10.44	10.08	10.27	0.14	0.441
ME per kg of BW	10.63	10.45	10.74	10.46	10.56	0.13	0.553
Overall period, Mcal/d							
NE intake.	7.08[ab]	6.96[abc]	7.10[a]	6.82[c]	6.89[bc]	0.08	0.035
NE_m[7]	2.68	2.67	2.69	2.65	2.66	0.02	0.294
NE for growth[8]	4.40[a]	4.29[ab]	4.41[a]	4.17[b]	4.23[b]	0.06	0.025

Table 2.8 continued

NE per kg of BW	7.42[a]	7.29[bc]	7.37[ab]	7.21[c]	7.28[bc]	0.04	0.010
NE per kg of carcass	9.94	10.01	10.02	9.94	9.93	0.06	0.640
ME intake	9.45	9.43	9.59	9.24	9.31	0.11	0.112
ME_m[9]	3.84	3.84	3.85	3.81	3.82	0.02	0.596
ME for growth[10]	5.67[ab]	5.63[ab]	5.78[a]	5.45[b]	5.52[b]	0.09	0.067
ME per kg of BW	9.90	9.89	9.96	9.76	9.84	0.06	0.188
ME per kg of carcass	13.26[a]	13.57[b]	13.54[b]	13.45[ab]	13.41[ab]	0.08	0.048

[1]Data are least mean squares (2,054 pigs in 95pens), analyzed using the Mixed procedure of SAS®

[a-c] Within a row, least mean squares without a common superscript letter differ ($P \leq 0.05$).

[2]Corn-soy based diet

[3]Control plus 30% of corn DDGS (25% for phase 1), ME equal to the corn-soy diet

[4]Control plus 30% of corn DDGS, (25% for phase 1) NE equal to the corn-soy diet

[5]Control plus 20% each of corn DDGS and corn germ meal, (25 and 15% respectively for phase 1), and ME equal to the corn-soy diet

[6]Control plus 20% each of corn DDGS and corn germ meal, (25 and 15% respectively for phase 1), and NE equal to the corn-soy diet

[7]Calculated as NEm (kcal/d) = (1)×(FHPx0.708+207)×(BW, kg)$^{0.6}$ (van Milgen et al., 2008).

[8]Calculated as ME for growth = NE intake – NE_m

[9]Calculated as MEm = 197*$EBW^{0.60}$ (NRC, 2012)

[10]Calculated as ME for growth = ME intake - MEm

CHAPTER III

DIGESTION AND NITROGEN BALANCE OF DIETS WITH INCREASING PROPORTIONS OF CO-PRODUCT INGREDIENTS AND FORMULATED USING THE NET ENERGY SYSTEM

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Abstract

Rising feed costs demand that our industry pursue strategies to lower the cost of production. One option is the adoption of the net energy system (NE), although many producers are hesitant to proceed without more definitive data. The objective of this experiment was to compare the apparent total tract digestibility (ATTD) of energy and nutrients and the nitrogen retention (NR) of diets formulated using the NE system with increasing quantities of co-product ingredients. The 5 dietary treatments included a control corn soybean meal-based control diet (Ctl), a diet similar to the Ctl but containing 6% each of corn distillers dried grains with soubles (DDGS), corn germ meal and wheat middlings with NE constant relative to CTL (Const-18), or allowed to decline (Decl-18), or similar diets but with 12% each of the same co-products and NE held constant (Const-36) or allowed to decline (Decl-36). Constant NE was achieved by adding soybean oil. Diets were formulated for both growing (40 to 70 kg; GP) and finishing (70 to 110 kg; FP) periods.

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Forty gilts (PIC 337 × C22 or C29; initial BW=38.5±0.4 kg) were randomly assigned to treatment and receiving feed and water *ad-libitum*. For the last 13d of the GP and FP, pigs were transferred to metabolism crates, where two total urine and fecal collections (d4 to 6; d11 to 13) were performed. Data were analyzed using the MIXED and the REG procedures of SAS. GP fed diets with co-product ingredients had lower ATTD of DM, nitrogen and GE than those fed the control diet ($P < 0.05$). The ATTD of nitrogen and GE decreased progressively as co-product inclusion increased from 0 to 18 to 36% in the FP ($P < 0.01$). In the GP and FP, there were no differences in ATTD of DM, nitrogen or GE between the pairs of Const and the Decl NE treatments ($P > 0.05$). In both (GP and FP) the ATTD of AEE increased as dietary AEE increased ($P < 0.01$). True total tract digestibility (TTTD) of AEE and endogenous loses of AEE was estimated to be between 107.3 to 92.3% and 18.7 to 25.9 g/kg of DMI respectively. NR declined on all co-product diets in the GP ($P = 0.01$) and tended to decline in the FP (P=0.08). There were no differences in NR between Const and Decl diets with the same level of co-product inclusion ($P > 0.05$). In conclusion, digestion of diets containing up to 36% co-products and formulated using NE resulted in expected DE and ME values; however, NR of diets with coproducts was lower than on the simple corn-soybean meal control diet.

Keywords: Pigs, net energy, DDGS, wheat middlings, corn germ meal, nitrogen retention

Introduction

Rising feed costs for swine demand that our industry pursue strategies to lower the cost of production. One of the most effective ways to respond to this demand is by including lower cost ingredients. However, one of the main challenges of including these materials is their lower

NE concentration. This occurs mainly because of a different profile of their chemical constituents, especially in the carbohydrate fraction; starch is usually lower and molecules related to dietary fiber are usually higher in concentration than in corn. Pigs are able to increase feed intake when fed low NE diets, but there is an upper limit to this capacity (Henry, 1985; NRC, 1998; Oresanya et al., 2008; Beaulieu et al., 2009; Quiniou and Noblet, 2012). If feed intake does not rise, and this is entirely possible under many commercial conditions, low NE diets will result in poorer growth performance (Quiniou and Noblet, 2012). To avoid this problem, NE concentration can be increased efficiently by adding a source of fat to the diet (Bakker, 1996), but this implies an increase in the cost. Therefore, to justify its use, added fat should enhance energy retention. In theory, diets with the same NE content should result in a similar tissue accretion despite having different chemical composition; in contrast, diets with a declining NE diets should result in a poorer tissue accretion.

The first objective of this experiment was to compare apparent total tract digestibility (ATTD) of DM, nitrogen (N), acid hydrolyzed ether extract (AEE) and GE in diets containing an increasing level of distiller grains, corn germ, and wheat middlings and formulated to a constant or declining NE value. The second objective was to test if nitrogen retention (NR) is equal when diets are formulated to an equal NE concentration.

Materials and methods

The protocol for this experiment was approved by the Institutional Animal Care and Use Committee of Iowa State University (U.S.12-12-7478-S).

Animals Housing and Experimental Design

This experiment was conducted at the Swine Nutrition Farm at Iowa State University (Ames, IA). Two groups of 20 gilts (initial BW 38.5±0.4 kg) of the progeny of PIC 337 sires × C22 or C29 dams (Hendersonville, TN) were randomly assigned to 1 of 5 treatments for 2 periods: a growing period (GP) from 39 to 70 kg, and a finishing period (FP) from 70 to 110 kg. Within each period, pigs were placed in individual pens for 21 days and then transferred to metabolism crates for 13 days. The average daily room temperature was 18°C and 16°C (for the growing and the finishing period, respectively). Each pen included a partially slatted concrete floor, an automatic dry self-feeder and a cup drinker. Each crate consisted of a fully slatted floor, stainless steel feeder, and a nipple drinker. Pigs had *ad libitum* access to feed and water during the entire experimental period.

Dietary treatments

Diets were manufactured using commercial sources of ingredients and according to the following specifications: a control diet containing corn and soybean meal (Ctl), a pair of diets with a medium level (6%) of each of 3 alternative ingredients (corn germ meal, corn DDGS and wheat middlings) –in which one diet had the same NE content as the Ctl by adding soybean oil (Const-18%), and the other diet with no soybean oil added allowing the NE to decline (Decl-18%), and another pair of diets with a higher level (12%) of inclusion of each of the same alternative ingredients – in which one diet had the same NE content as the Ctl by adding soybean oil (Const-36%), and the other with no soybean oil added and NE allowed to decline (Decl-36%).

Amino acids, phosphorous and calcium levels were set at 6% above NRC 2012 requirements for both growing (40 to 70 kg) and finishing (70 to 110 kg) gilts. In this way, energy could be considered the only limiting factor for nitrogen retention. Additionally, titanium dioxide was included at 0.4% as an indigestible marker. All diets were provided in mash form.

Data and samples

Prior to formulating the diets, samples of corn, soybean meal, corn DDGS, corn germ meal, and wheat middlings were finely ground and analyzed at the Agricultural Experiment Station Chemical Laboratories (University of Missouri-Columbia, MO) and Monogastric Nutrition Laboratory (Iowa State University-Ames, IA). Ingredients were ground through a 1 mm screen in a Retsch grinder (Model ZM1, Retsch Inc., Newton, PA) and tested for DM (Method 930.15; AOAC, 2007), starch (modified method 996.11, AOAC 1996), crude protein as nitrogen × 6.25 (determined using Kjeldahl AOAC official method 984.13 A-D, 2006), ADF and NDF determined according to Van Soest and Robertson (1979) and acid hydrolyzed ether extract (AEE; method 2003.06, AOAC International, 2007). Values provided from these assays as well as the ME values published in the NRC, 2012 were used to estimate NE according to equation 1-7 (NRC, 2012):

$$NE = (0.726 \times ME) + (1.33 \times AEE) + (0.39 \times Starch) - (0.62 \times CP) - (0.83 \times ADF)$$

where energy is expressed in kcal/kg and other nutrients in g/kg.

All the remaining specifications of ingredients were taken from the NRC 2012 feed ingredient composition tables.

Complete diet samples were collected at the feed mill at the time of mixing and again during the feeding period. Total fecal and total urine samples were collected by placing a metal

tray, a screen and a plastic jug under each crate. Samples were collected during days 4-6 and 11-13, allowing pigs to have 3 days to adapt to the metabolism crate. Urine and feces were collected twice daily and stored at -20°C until further processed. Feces were collected in a pre-labeled plastic bag, while all the urine was collected in a plastic jug (with ≈20ml of 6*N* hydrochloric acid added before each collection to minimize nitrogen losses due to ammonia volatilization). Urine pH was measured at each collection using a pH paper indicator to ensure a pH below 2.0 to minimize nitrogen losses. Total urine output was filtered and 10% subsampled for nitrogen analysis. At the end of the collection, fecal samples were homogenized, subsampled, dried in an oven at 105°C, and finely ground through a 1 mm screen in a Wiley grinder (Model ED-5, Thomas Scientific Inc., Swedesboro, NJ). Feed samples were ground through a 1 mm screen in a Retsch grinder (Model ZM1, Retsch Inc., Newton, PA). Both fecal and feed samples were stored in plastic bags in desiccator cabinets while urine samples were kept at -20C until chemical assays were performed.

Samples of feed and feces were analyzed for concentration of DM (method 930.15; AOAC, 2007), nitrogen by thermo-combustion (method 990.03, AOAC International, 2007; Leco TruMac N, LECO Corporation, St. Joseph, MI). EDTA (9.56% nitrogen; Leco Corporation, St. Joseph, MI) was used as a standard for calibration and was determined to be 9.58 ± 0.01. AEE (method 2003.06, AOAC International, 2007) was analyzed using a SoxCap SC 247 hydrolyzer and a Soxtec 255 semiautomatic extractor, (FOSS North America, Eden Prairie, MN). Gross energy was determined using a Parr bomb calorimeter 6200 (Parr Instrument Co., Moline, IL). Benzoic acid (6,318 kcal/kg; Parr instruments, Moline, IL) was used as a standard for calibration and was determined to be 6,323 ± 8 kcal/kg. Titanium dioxide was determined using a Synergy 4 spectrophotometer (BioTek, Winooski, VT), according to the

method of Leone (1973). Amino acid analyses of diets were determined by wet chemistry at the Evonik-Degussa Laboratory (Kennesaw, GA) using a HPLC procedure after acid hydrolysis for most amino acids or by performic acid oxidation with acid hydrolysis- for sulfur amino acids (method 994.12; AOAC International, 2002). Tryptophan content was determined after alkaline hydrolysis.

Calculations

ATTD of DM, nitrogen, AEE, and GE was calculated using the equation: ATTD, % = [100 – [100 × (% TiO_2 in feed / % TiO_2 in feces) × (concentration of component in feces / concentration of component in feed)]] (Oresanya et al., 2008). The ATTD of added soybean oil was calculated by difference using the diets without oil added (Decl-18 and Decl-36) as the baseline for non-added oil digestion (intact fat).

True total tract digestibility (TTTD) of AEE, and endogenous losses of AEE of were estimated for each pig in diets with intact fat (Ctl, Decl-18 and Decl-36) and for each pig on diets with intact and added fat (Ctl as level 0 of extracted fat, Const-18 and Const-36) using regression analysis of dietary AEE intake (g/kg of DM) against apparent digested AEE (g/kg of DMI) according to Jørgensen et al. (1993).

DE was calculated by multiplying GE concentration by the ATTD of GE, ME was calculated by subtracting urinary energy from DE (calculation of methane loses were omitted in this calculation due to a lack of a reliable equation and its relatively small contribution to the calculation (Kil, 2013). Urinary energy was calculating using the equation proposed by Noblet and van Milgen (2004):

Urinary energy = 192 +31 × Urinary nitrogen

were urinary energy is in kJ/kg DMI and urinary nitrogen in g/kg DMI and then transformed to kcal using the conversion factor (1 kJ = 0.2390 kcal).

Nitrogen intake was calculated by multiplying nitrogen in the feed (DM basis) by DMI, nitrogen excreted in the urine was calculated by multiplying the average daily volume of urine times the average urinary nitrogen concentration. Nitrogen excreted in feces was calculated by multiplying the nitrogen intake times the ATTD of nitrogen. Nitrogen excretion was calculated as the sum of nitrogen excreted in urine and nitrogen excreted in the feces per day. Finally nitrogen retention was calculated by the difference between nitrogen excretion and intake.

Statistical analysis

The UNIVARIATE procedure of SAS (SAS Inst., Inc., Cary, NC) was used to test for normality and extreme values. The MIXED procedure of SAS was used including treatment as fixed effect and replicate as a random effect in the model. Multiple comparisons among treatments were determined using the protected LSD test, when the overall treatment effect was significant. The REG procedure of SAS was used to estimate endogenous AEE losses and TTTD of AEE. The slopes of the regression lines and the intercepts were compared based on confidence intervals of coefficients for regression lines. Differences among treatments were considered statistically significant with $P \leq 0.05$ and trends with $P > 0.05$ to $P \leq 0.10$. Since they were housed individually, pig was the experimental unit for all analyses.

Results

Chemical analysis of ingredients for CP, starch, EE, ADF and NDF were in agreement with the NRC, (2012). Resulting NE values utilized were very close to those reported in the NRC, (2012).

ATTD of DM, nitrogen, AEE and GE

In the GP, feeding diets with coproduct ingredients resulted in lower ATTD of DM, nitrogen and GE compared with the control diet (Table 6; $P < 0.05$). Additionally, there were no differences in these same outcomes between the constant and the declining NE treatments within the same level of co-product inclusion ($P > 0.05$). The ATTD of AEE increased as dietary AEE increased ($P < 0.01$). By difference, the ATTD of added fat was higher than the ATTD of intact fat.

In the FP, the ATTD of DM, nitrogen and GE decreased progressively from 0 to 18 to 36% co-product inclusion (Table 7; $P < 0.01$). There were no differences in these same outcomes between the constant and the declining NE treatments with the same level of co-product inclusion ($P > 0.05$). The ATTD of AEE increased as dietary AEE increased ($P < 0.01$). By difference, the ATTD of added fat was higher than the ATTD of intact fat.

Energy values

Determined GE in the growing period was greater in diets with co-products than the control diet. Additionally, Const-18 and Const-36 diets were higher in GE than Decl-18 and Decl-36 diets due to the added fat (Table 6). As expected, the determined DE and calculated ME and NE were similar ($P > 0.05$) in Const-18 and Const-36, but lower ($P < 0.05$) in Decl-18 and Decl-36 treatments compared with the control diet.

Determined GE in the finishing period was greater in diets with co-products than the control diet (Table 7). In addition, Const-18 and Const-36 diets were higher in GE than Decl-18 and Decl-36 diets. Determined DE and calculated ME and NE were similar ($P > 0.05$) in Const-18 and Const-36, but lower ($P < 0.05$) in Decl-18 and Decl-36 treatments compared with the

control diet. Within co-product diets, Const-18 was not significantly different in determined DE and calculated ME and NE than Decl-18 ($P > 0.05$), but for these same variables Const-36 was greater than Decl-36 ($P < 0.05$).

Estimation of AEE intestinal endogenous loses and TTTD of AEE

In the GP, a linear increase in the apparent digested AEE resulted in a greater intake of AEE in diets with by-product ingredients (Table 8; $P < 0.001$, $r^2=0.86$). Endogenous losses of AEE were estimated to be 25.9g/kg/DMI and the estimation of the TTTD of AEE in the basal ingredients, which are referred to as innate fat was 107.3%. Using the same approach for added fat diets, a linear increase of apparent digested AEE was observed as the intake of added fat increased ($P < 0.001$, $r^2=0.99$). Endogenous loses were estimated to be 22.7g/ kg/DMI and the estimate of the TTTD of added fat was 98.5%.

In the FP, a linear increase in the apparent digested AEE resulted in a greater intake of AEE in diets with by-product ingredients ($P <0.001$, $r^2=0.90$). Endogenous loses for innate fat sources were estimated to be 18.7g/ kg DMI and the estimated TTTD of AEE was 92.3%. Similarly, a linear increase of apparent digested AEE was observed as the intake of added fat increased ($P <0.001$, $r^2=0.99$). Endogenous loses were estimated to be 19.9g/ kg/DMI and the TTTD of added fat was 94.2%.

Nitrogen balance

In the GP, daily nitrogen intake was higher on Decl-36 than in pigs fed the Const-18, Const-36 and the control diet (Table 9; $P <0.05$), while Decl-18 represented an intermediate value. Total daily nitrogen excretion was higher in pigs fed Decl-36 than the rest of the treatments ($P < 0.05$), except for Decl-18 that presented an intermediate value. Daily fecal

nitrogen excretion was higher in pigs fed Decl-36, Const-36 and Decl-18 than those fed the control diet, while Const-18 presented an intermediate value. Total daily urinary nitrogen excretion was not different among treatments ($P = 0.115$). Total daily nitrogen retention tended to differ among treatments ($P = 0.066$); retention was similar for pigs fed Decl-18 and Decl-36 compared with the control diet ($P > 0.05$), but it was lower for Const-18 and Const-36 diets ($P < 0.10$).

The percentage of nitrogen excreted was lower in pigs fed the control diet than the rest of the treatments ($P < 0.05$); in the opposite way, the percentage of nitrogen retained was higher in pigs fed the control diet than pigs on the rest of the treatments ($P < 0.05$). Partitioning of the nitrogen excretion shows that the control diet resulted in lower fecal nitrogen excretion than the rest of the treatments ($P < 0.05$), while urinary excretion was similar among treatments ($P > 0.05$).

In the FP, daily nitrogen intake was higher in pigs fed Ctl, Decl-18 and Decl-36 compared with Const-18 and Const-36 (Table 10; $P < 0.05$). Total daily nitrogen excretion was higher in pigs fed Decl-36 and Decl-18 than those fed any of the other treatments ($P < 0.05$). Daily fecal nitrogen excretion was highest in pigs fed Decl-36, followed by Const-36 and Decl-18 and lowest for Const-18 and the control diet ($P < 0.05$). Total daily urinary nitrogen excretion tend to differ among treatments ($P = 0.076$), being greater for Decl-18 than Const-18 and Const-36 ($P < 0.05$), and intermediate for Decl-36 and the control diet. Daily nitrogen retention was greater for pigs fed Decl-18, Decl-36 and the control diet ($P > 0.05$), than for Const-18 ($P < 0.05$).Const-36 was intermediate between Const-18 and Decl-16 ($P > 0.05$), but lower than Decl-18 and the control diet ($P < 0.05$)

Percentage of nitrogen excreted tended to differ among treatments ($P = 0.079$), being lower in pigs fed the control diet than the rest of the treatments ($P < 0.05$); in the opposite way the percentage of nitrogen retained tended to be higher in pigs fed the control diet than pigs on the rest of the treatments ($P < 0.05$).

Discussion

Dietary GE concentration is determined by the profile of carbohydrates, lipids and proteins (NRC, 2012). In this experiment, GE was progressively higher with the addition of co-products than the corn soy diet than the corn-soy diet dietary fat and protein (5.6 and 9.4 calories per gram respectively) were higher, while starch (4.2 calories per gram) was lower in diets with co-products than for the corn-soy control. On the other hand, the change in the proportions of the carbohydrate fraction (higher dietary fiber and lower starch for diets with co-products) did not alter the GE concentration because the GE values of fiber and starch are the same (4.2 calories per gram; NRC, 2012). As expected, the difference in GE between the constant and declining NE diets is explained by the higher fat content provided by the addition of soybean oil.

Usable energy derived from GE is determined in part by the digestibility of nutrients (Bakker, 1996). Measurement of the ATTD of GE confirmed that the non-digested fraction is larger in diets with co-products, which is driven by the increase in the fiber fraction (Noblet and Shi, 1993; Whittemore, 1997; Le Goff and Noblet, 2001; Urriola and Stein, 2010; Gutierrez et al., 2013). Digestible energy from fiber relies on microbial fermentation, specifically the production of short chain fatty acids which is limited in pigs (Zijlstra et al., 2012; Zhang et al., 2013). Additionally, production of short chain fatty acids represents an energy loss since during microbial synthesis, energy is released as heat (Kohn, 2008). On the other hand, fiber may also

increase endogenous secretions (Schulze et al., 1995) or may reduce the digestion and absorption of other dietary components (Milgen, 2006). In this experiment, the ATTD of nitrogen decreased in the same fashion as the ATTD of GE, suggesting either an interference by fiber of AA absorption or higher AA endogenous loses as co-product levels increased. Interestingly, this experiment is in close agreement with Gutierrez et al. (2013), who obtained similar results in terms of apparent nitrogen and energy digestion with increasing levels of corn bran with solubles with constant and declining NE diets.

The addition of oils and/or animal fats to diets is essential if the goal is to increase the energy concentration of diets. Additionally, these ingredients are expected to increase the digestibility of GE due to its highly digestible composition (NRC, 2012), and an associated increase in retention time of digesta in the gastrointestinal tract (Valaja and Siljander-Rasi, 2001). In this experiment, the inclusion of soybean oil (1.7 and 3.3%) failed to increase the ATTD of GE (constant NE diets vs declining NE diets). Although Kil et al. (2011, 2013) reported greater digestion of GE with a higher level of added soybean oil (5, 8 and 10%), Jørgensen et al. (1993), with soybean oil inclusions closer to the range of this current study (0.5 to 3% added to a fat free basal diet) reported no significant differences in the ATTD of GE. Therefore, a possible reason for no change in the ATTD of GE with added fat is the small quantity added and an inability to detect differences in this size of experiment. Nonetheless, the digestible energy content of the diets with added fat were observed herein, but this would have been due, in part, to the higher GE of the diets. The objective of the diet formulations - to maintain constant DE, ME and NE through the addition of fat to the higher fiber diets - was accomplished in both GP and FP.

Looking specifically to the digestion of fat, there were large differences in the ATTD of AEE among diets. Additionally, the ATTD of added soybean oil was greater than the ATTD of the fat which naturally occurred in the ingredients. Similar results were obtained by Kil et al. (2011), who compared 5 and 10% soybean oil addition to a corn-soy diet. However, since intestinal endogenous losses represent a larger proportion of the total fecal AEE in pigs fed diets with less AEE (Kil et al., 2010), it becomes necessary to estimate the TTTD of AEE. Otherwise, the digestibility of fat that is innate in ingredients may be underestimated. To estimate endogenous fat losses, a linear relationship between the dietary level of AEE and the apparent digested AEE was determined. Using this approach, our estimated endogenous losses were greater than reported in some other studies (18.7 to 25.9 g/kg of DMI compared to 4.4 g/kg DMI, Jørgensen et al., 1993; 3.3 to 12.1g/kg DMI, Kil et al., 2010 and 0 to 6.51 g/kg DMI, Kim et al., 2013) but less than in others (33.0 and 30.6g/kg of DMI; Freeman et al., 1968; Adams and Jensen, 1985). Differences from other studies compared to this study can be the result of different experimental methodologies, specifically diet composition (complete diets vs. incomplete diets) and feed allowance (ad-libitum vs. restricted). In terms of energy, and using the extreme values of 95% confidence intervals, endogenous loses from 15.2 to 30.7g/kg of DMI could represent an energetic cost to the pig of 137 to 276 kcal/kg of DMI (assuming 9 cal/g of fat).

Diets containing increasing levels of co-products and formulated to a constant or declining NE concentration provided an expected equivalence of DE, ME and NE concentration, supporting the ability of the NE system to accurately predict energy utilization.

Dietary energy and protein are closely related because protein is a source of energy, because energy is needed for protein turnover and deposition, and because protein is part of the

energy retained in the body (Boorman, 1980). Lawrence et al., (1994) reported a close relationship between nitrogen retention and DE. In this experiment, constant NE diets were formulated to a same Lys:NE ratio, as well as a similar NE, to achieve the same level of nitrogen retention. However, nitrogen retention in growing and in finishing pigs was lower when pigs were fed diets with coproducts compared to pigs fed a corn soybean meal diet. There are 2 possible explanations: an insufficient amino acid supply or an insufficient energy supply.

Amino acid analysis of the diets was performed in order to confirm SID specifications and ratios listed in the NRC (2012); this was achieved. However, a possible reason for a lower nitrogen retention could be related to a slightly lower SID values for Lys in the constant NE diets than the corn soy diet. Supply of dietary energy seems to be an unlikely cause since DE, ME and NE values were similar across the "constant NE" diets. A more likely explanation could be errors in the equations used to estimate dietary NE levels. An alternative possibility is related to the regulation of protein synthesis in skeletal muscle. Suryawan et al. (2007) suggested that protein synthesis in skeletal muscle is associated with increased activation of insulin-signaling components after a postprandial increase in glucose, indicating that a requirement exists for sufficient glycemic and insulinemic responses for efficient nitrogen retention (Drew et al., 2012). In this experiment, coproduct diets were considerably lower in starch content than the corn soybean meal diet. However, to the best of our knowledge, it has not yet been shown that starch levels employed in this study would be insufficient to induce glycemix and insulinemic responses.

In conclusion, the digestion of diets containing increasing levels of co-products and formulated to a constant NE concentration resulted in for the expected equivalence of DE, ME and NE concentration. However, nitrogen retention was not maintained, an unexpected outcome. This response may be related to an inadequate amino acid supply, to errors in the equations used to estimate NE or to the dynamics of the protein synthesis regarding energy availability.

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Table 3.1 Analyzed ingredient composition and calculation of NE values for the ingredients utilized in the experimental diets (as-fed basis).

Ingredient	Corn	Soybean meal	Corn DDGS	Corn germ meal	Wheat middlings
Composition, %					
DM	86.7	89.5	91.1	89.2	89.3
CP	8.6	47.2	27.2	25.0	17.1
AEE	3.5	1.5	10.0	3.0	3.8
Starch	61.1	2.0	4.1	18.0	14.1
ADF	1.6	4.0	12.1	9.7	11.8
NDF	5.9	5.7	24.5	36.5	35.5
NE, Mcal/kg					
Calculated[1]	2.713	1.958	2.298	1.873	2.020
NRC, 2012 table	2.672	2.087	2.384	1.888	2.113

[1] From NRC 2012, Equation [1-7]

Table 3.2 Ingredient composition (%) of experimental diets fed to pigs in the growing period (as-fed basis).

Item	Ctl[1]	Const-18[2]	Decl-18[3]	Const-36[4]	Decl-36[5]
Corn	72.39	56.46	58.25	40.58	44.06
Soybean meal	23.90	20.40	20.27	16.89	16.64
Corn DDGS	-	6.00	6.00	12.00	12.00
Corn germ	-	6.00	6.00	12.00	12.00
Wheat middlings	-	6.00	6.00	12.00	12.00
Soybean oil	-	1.66	-	3.32	-
L-lysine HCl	0.30	0.30	0.30	0.30	0.30
DL-methionine	0.06	0.01	0.01	-	-
L-threonine	0.08	0.06	0.06	0.05	0.05
Monocalcium phosphate	0.91	0.63	0.62	0.34	0.33
Limestone	1.15	1.27	1.28	1.40	1.41
Salt	0.50	0.50	0.50	0.50	0.50
Vitamin premix[6]	0.16	0.16	0.16	0.16	0.16
Trace mineral premix[7]	0.15	0.15	0.15	0.15	0.15
Titanium dioxide	0.40	0.40	0.40	0.40	0.40

[1]Corn-soy based diet

[2]Control plus 6% each of corn DDGS, corn germ meal, and wheat middlings, and NE equal to the control diet

[3]Const-18, without fat added, NE content lower than control diet

[4]Control plus 12% each of corn DDGS, corn germ meal, and wheat middlings, and NE equal to the control diet

[5]Const-36, without fat added, NE content lower than control diet

[6]Provided the following (unit/kg diet): 4,900 IU of vitamin A; 560 IU of vitamin D_3; 40 IU of vitamin E; 2.4 mg of menadione (to provide vitamin K); 39 μg of vitamin B_{12}; 9 mg of riboflavin; 22 mg of d-pantothenic acid; and 45 mg of niacin

[7]Provided the following (unit/kg diet): 165 mg of Fe (ferrous sulfate); 165 mg of Zn (zinc sulfate); 39 mg of Mn (manganese sulfate); 2 mg of Cu (cooper sulfate); 0.3 ppm of I (calcium iodate); and 0.3 ppm of Se (sodium selenite)

Table 3.3 Energy and nutrient levels (as-fed basis) of experimental diets fed to pigs in the growing period[1].

Item	Ctl[2]	Const-18[3]	Decl-18[4]	Const-36[5]	Decl-36[6]
CP, %[7]	18.15	18.94	19.24	19.97	20.20
ADF, %[8]	2.10	3.90	3.90	5.70	5.70
NDF, %[8]	5.60	10.30	10.40	15.10	15.30
Starch, %[8]	44.70	37.07	38.16	29.47	31.59
AEE, %[7]	2.91	4.89	3.30	7.01	3.79
SID AA %[9]					
Lys	1.03	1.00	0.99	0.93	0.93
Thr	0.61	0.61	0.62	0.63	0.62
Met	0.28	0.31	0.25	0.26	0.26
TSAA	0.50	0.56	0.49	0.50	0.51
Trp	0.19	0.20	0.18	0.18	0.18
SID AA: Lys ratio					
Lys	100	100	100	100	100
Thr	60	61	63	67	67
Met	27	31	25	28	28
TSAA	49	56	49	54	54
Trp	18	20	19	20	20
Ca, %[8]	0.69	0.69	0.69	0.69	0.69
P total, %[8]	0.55	0.58	0.58	0.61	0.61
STTD, P %[8]	0.32	0.32	0.32	0.32	0.32
NE, Mcal/kg	2.43	2.43	2.35	2.43	2.27
ME, Mcal/kg	3.25	3.29	3.20	3.33	3.15
NE:ME ratio	0.75	0.74	0.73	0.73	0.72

[1]Amino acids levels, STTD phosphorous and calcium at 6% above NRC 2012 requirements for 35-65 kg gilts

[2]Corn-soy based diet

[3]Control plus 6% each of corn DDGS, corn germ meal, and wheat middlings, and NE equal to the control diet

[4]Const-18, without fat added, NE content lower than control diet

[5]Control plus 12% each of corn DDGS, corn germ meal, and wheat middlings, and NE equal to the control diet

[6]Const-36, without fat added, NE content lower than control diet

[7]Values from laboratory assays

[8]Values from the diet formulation

[7]Calculated from results of dietary amino acids assays multiplied by the SID of amino acids published in the NRC, 2012

Table 3.4 Ingredient composition (%) of experimental diets fed to pigs in the finishing period (as-fed basis).

Item	Ctl[1]	Const-18[2]	Decl-18[3]	Const-36[4]	Decl-36[5]
Corn	79.61	63.66	65.45	47.67	51.26
Soybean meal	16.95	13.44	13.31	9.93	9.68
Corn DDGS	-	6.00	6.00	12.00	12.00
Corn germ	-	6.00	6.00	12.00	12.00
Wheat middlings	-	6.00	6.00	12.00	12.00
Soybean oil	-	1.67	-	3.33	-
L-lysine HCl	0.30	0.30	0.30	0.30	0.30
DL-methionine	0.03	-	-	-	-
L-threonine	0.07	0.06	0.06	0.05	0.04
Monocalcium phosphate	0.80	0.52	0.51	0.23	0.22
Limestone	1.03	1.15	1.16	1.28	1.28
Salt	0.50	0.50	0.50	0.50	0.50
Vitamin premix[6]	0.16	0.16	0.16	0.16	0.16
Trace mineral premix[7]	0.15	0.15	0.15	0.15	0.15
Titanium dioxide	0.40	0.40	0.40	0.40	0.40

[1]Corn-soy based diet

[2]Control plus 6% each of corn DDGS, corn germ meal, and wheat middlings, and NE equal to the control diet

[3]Const-18, without fat added, NE content lower than control diet

[4]Control plus 12% each of corn DDGS, corn germ meal, and wheat middlings, and NE equal to the control diet

[5]Const-36, without fat added, NE content lower than control diet

[6]Provided the following (unit/kg diet): 4,900 IU of vitamin A; 560 IU of vitamin D_3; 40 IU of vitamin E; 2.4 mg of menadione (to provide vitamin K); 39 μg of vitamin B_{12}; 9 mg of riboflavin; 22 mg of d-pantothenic acid; and 45 mg of niacin.

[7]Provided the following (unit/kg diet): 165 mg of Fe (ferrous sulfate); 165 mg of Zn (zinc sulfate); 39 mg of Mn (manganese sulfate); 2 mg of Cu (cooper sulfate); 0.3 ppm of I (calcium iodate); and 0.3 ppm of Se (sodium selenite)

Table 3.5 Energy and nutrient content (as-fed basis) of experimental diets fed to pigs in the finishing period[1].

Item	Ctl[2]	Const-18[3]	Decl-18[4]	Const-36[5]	Decl-36[6]
CP, %[7]	14.78	15.99	15.95	17.21	17.46
ADF, %[8]	2.00	3.70	3.80	5.50	5.60
NDF, %[8]	5.70	10.40	10.50	15.10	15.30
Starch, %[8]	48.97	41.33	42.42	33.66	35.85
AEE, %[7]	3.02	5.11	3.51	7.10	3.89
SID AA %[9]					
Lys	0.80	0.78	0.80	0.77	0.76
Thr	0.49	0.51	0.50	0.52	0.52
Met	0.23	0.21	0.22	0.24	0.23
TSAA	0.41	0.41	0.42	0.46	0.45
Trp	0.14	0.14	0.15	0.15	0.15
SID AA: Lys ratio					
Lys	100	100	100	100	100
Thr	61	65	63	68	68
Met	28	27	27	31	30
TSAA	52	53	53	60	59
Trp	17	18	18	19	20
Ca, %[8]	0.60	0.60	0.60	0.60	0.60
Total, P %[8]	0.50	0.52	0.53	0.55	0.56
STTD, P %[8]	0.28	0.28	0.28	0.28	0.28
NE, Mcal/kg	2.49	2.49	2.41	2.48	2.32
ME, Mcal/Kg	3.26	3.30	3.21	3.34	3.17
NE:ME ratio	0.77	0.76	0.76	0.76	0.75

[1] Amino acids levels, STTD phosphorous and calcium at 6% above NRC 2012 requirements for 65-100 kg gilts

[2]Corn-soy based diet

[3]Control plus 6% each of corn DDGS, corn germ meal, and wheat middlings, and NE equal to the control diet

[4]Const-18, without fat added, NE content lower than control diet

[5]Control plus 12% each of corn DDGS, corn germ meal, and wheat middlings, and NE equal to the control diet

[6]Const-36, without fat added, NE content lower than control diet

[7]Values from laboratory assays

[8]Values from the diet formulation

[9]Calculated from results of dietary amino acids assays multiplied by the SID of amino acids published in the NRC, 2012

Table 3.6 Apparent total tract digestibility (ATTD) and energy content determined in the growing period[1].

Item	Ctl[2]	Const-18[3]	Decl-18[4]	Const-36[5]	Decl-36[6]	SEM	*P*-Value
ATTD, %							
DM	86.2[a]	82.3[b]	81.3[bc]	79.2[cd]	78.9[d]	0.6	0.002
Nitrogen	84.9[a]	81.2[b]	79.8[b]	78.5[b]	78.4[b]	1.0	0.023
AEE diet	29.6[e]	56.8[b]	36.0[d]	69.8[a]	47.5[c]	1.0	<0.001
Added oil		96.0		94.8		-	-
Intact fat	29.6	36.0	36.0	47.5	47.5	-	-
GE	85.3[a]	81.8[b]	80.5[bc]	79.2[bc]	78.1[c]	0.7	0.005
Energy Mcal/kg, DM							
GE	4.34	4.50	4.41	4.62	4.42	-	-
DE	3.70[a]	3.68[a]	3.55[bc]	3.66[ab]	3.45[c]	0.03	0.011
ME[7]	3.53[a]	3.50[a]	3.38[b]	3.49[a]	3.27[b]	0.03	0.007
NE[8]	2.66[a]	2.64[a]	2.53[bc]	2.62[ab]	2.45[c]	0.03	0.011

[a,b,c,d,e] Superscripts assess significant differences (P>0.05) or statistical trends (P>0.10) between dietary treatments

[1]Data are least mean squares of 40 gilts, with 8 animals per treatment, analyzed using the Mixed procedure of SAS®

[2]Corn-soy based diet

[3]Control plus 6% each of corn DDGS, Corn germ meal, and wheat middlings, and NE equal to the control diet

[4]Const-18, without fat added, NE content lower than control diet

[5]Control plus 12% each of corn DDGS, corn germ meal, and wheat middlings, and NE equal to the control diet

[6]Decl-36= Const-36, without fat added, NE content lower than control diet

[7]ME= DE-urinary energy. Urinary energy was calculated using Noblet et al., (2004) equation: Urinary energy kJ/kg DMI = 192 + 31 × urinary nitrogen g/kg DMI

[8]Noblet et al., (1994) equation 3: $NE = 0.843 \times DE - 463$

Table 3.7 Apparent total tract digestibility (ATTD) and energy content determined for finishing period, diets contained 0, 18 or 36% of co-products, with a constant or declining NE content[1].

Item	Ctl[2]	Const-18[3]	Decl-18[4]	Const-36[5]	Decl-36[6]	SEM	*P*-Value
ATTD, %							
DM	87.9[a]	84.6[b]	85.0[b]	81.5[c]	81.3[c]	0.4	<0.001
Nitrogen	86.2[a]	83.1[b]	83.1[b]	80.8[c]	79.7[c]	0.5	0.002
AEE	36.0[d]	59.2[b]	47.2[c]	69.4[a]	48.2[c]	0.9	<0.001
Added oil		83.2		93.8		-	-
Intact fat	36.0	47.2	47.2	48.2	48.2	-	-
GE	87.1[a]	83.9[b]	84.3[b]	81.4[c]	80.6[c]	0.4	0.001
Energy Mcal/kg, DM							
GE	4.28	4.46	4.37	4.62	4.44	-	-
DE	3.72[ab]	3.74[ab]	3.68[b]	3.76[a]	3.58[c]	0.02	0.006
ME calculated [7]	3.56[a]	3.57[ab]	3.51[b]	3.58[a]	3.41[c]	0.02	0.004
NE[8]	2.68[ab]	2.69[ab]	2.64[b]	2.70[a]	2.56[c]	0.02	0.006

[a,b,c,d] Superscripts assess significant differences ($P>0.05$) or statistical trends ($P>0.10$) between dietary treatments

[1]Data are least mean squares of 40 gilts, with 8 animals per treatment, analyzed using the Mixed procedure of SAS®

[2]Corn-soy based diet

[3]Control plus 6% each of corn DDGS, corn germ meal, and wheat middlings, and NE equal to the control diet

[4]Const-18, without fat added, NE content lower than control diet

[5]Control plus 12% each of corn DDGS, Corn germ meal, and wheat middlings, and NE equal to the control diet

[6]Const-36, without fat added, NE content lower than control diet

[7]ME= DE-urinary energy. Urinary energy was calculated using (Noblet and van Milgen, 2004) equation: Urinary energy kJ/kg DMI = 192 + 31 x urinary nitrogen g/kg DMI

[8]Noblet et al., (1994) equation 3: NE = 0.843 x DE – 463

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Table 3.8 Estimated intestinal endogenous loses of AEE and TTTD of AEE in diets containing fat innate in ingredients or diets extracted fat added in growing and finishing pigs[1].

Item	Regression equation	r^2	Endogenous loses of AEE				TTTD of AEE			
			Estimate	*P*-value	95% CL		Estimate	*P*-value	95% CL	
Growing pigs										
AEE innate in ingredients	y=1.073x -25.88	0.86	25.9	<0.001	21.1	30.7	107.3	<0.001	94.7	120.0
Extracted AEE added	y=0.985x -22.73	0.99	22.7	<0.001	21.5	24.0	98.5	<0.001	96.3	100.7
Finishing pigs										
AEE innate in ingredients	y=0.923x -18.73	0.90	18.7	<0.001	15.2	22.3	92.3	<0.001	83.3	101.3
Extracted AEE added	y=0.942x -19.88	0.99	19.9	<0.001	18.5	21.3	94.2	<0.001	91.9	96.6

[1]Data was analyzed with the REG procedure of SAS using dietary AEE intake (g/kg of DM) against apparent digested AEE (g/kg of DMI)

Table 3.9 Effect of constant and declining NE formulated diets with 0, 18 and 36% of co-product addition on nitrogen balance in growing pigs[1].

Item	Ctl[2]	Cons-18[3]	Decl-18[4]	Const-36[5]	Decl-36[6]	SEM	*P*-Value
Nitrogen balance, g/d							
Intake	81.2[b]	79.0[b]	83.7[ab]	80.3[b]	90.6[a]	2.3	0.077
Total excreted	48.5[b]	51.4[b]	53.6[ab]	50.8[b]	59.6[a]	1.7	0.034
Fecal	12.4[c]	15.0[bc]	17.0[ab]	17.2[ab]	19.8[a]	0.8	0.009
Urinary	36.1	36.4	36.6	33.6	39.8	1.2	0.115
Net retained	32.8[a]	27.6[c]	30.1[abc]	29.4[bc]	31.1[ba]	0.9	0.066
Nitrogen balance, %							
Intake	100.0	100.0	100.0	100.0	100.0	-	-
Total excreted	59.4[b]	65.2[a]	64.0[a]	63.4[a]	65.6[a]	0.7	0.009
Fecal	15.1[b]	18.8[a]	20.2[a]	21.5[a]	21.6[a]	1.0	0.024
Urinary	44.3	46.4	43.8	41.9	44.0	1.1	0.198
Net retained	40.6[a]	34.8[b]	36.0[b]	36.6[b]	34.4[b]	0.7	0.009

[a,b,c] Superscripts assess significant differences ($P>0.05$) or statistical trends ($P>0.10$) between dietary treatments

[1]Data are least mean squares of 40 gilts, with 8 animals per treatment, analyzed using the Mixed procedure of SAS®

[2]Corn-soy based diet

[3]Control plus 6% each of corn DDGS, corn germ meal, and wheat middlings, and NE equal to the control diet

[4]Const-18, without fat added, NE content lower than control diet

[5]Control plus 12% each of corn DDGS, corn germ meal, and wheat middlings, and NE equal to the control diet

[6]Const-36, without fat added, NE content lower than control diet

Table 3.10 Effect of constant and declining NE formulated diets with 0, 18 and 36% of co-product addition on nitrogen balance in finishing pigs[1].

Item	Ctl[2]	Cons-18[3]	Decl-18[4]	Const-36[5]	Decl-36[6]	SEM	*P*-Value
Nitrogen balance, g/d							
Intake	81.2^{bc}	73.7^{d}	86.2^{ba}	76.0^{cd}	87.7^{a}	1.7	0.009
Total excreted	53.0^{b}	51.8^{b}	59.3^{a}	54.1^{b}	61.3^{a}	1.4	0.017
Fecal	11.3^{c}	12.6^{c}	14.6^{b}	14.7^{b}	17.9^{a}	0.5	0.001
Urinary	41.7^{ab}	39.2^{b}	44.6^{a}	39.4^{b}	43.4^{ab}	1.2	0.076
Net retained	28.2^{a}	22.0^{c}	27.0^{a}	22.7^{bc}	26.5^{ba}	1.1	0.036
Nitrogen balance, %							
Intake	100.0	100.0	100.0	100.0	100.0	-	-
Total excreted	65.0^{b}	70.0^{a}	68.8^{ab}	70.6^{a}	69.7^{a}	1.1	0.079
Fecal	13.8^{c}	16.9^{b}	16.9^{b}	19.2^{a}	20.3^{a}	0.5	0.002
Urinary	51.2	53.2	51.9	51.5	49.5	1.2	0.393
Net retained	35.0^{a}	30.0^{b}	31.2^{ab}	29.4^{b}	30.3^{b}	1.1	0.079

[a,b,c,d] Superscripts assess significant differences (P>0.05) or statistical trends (P>0.10) between dietary treatments

[1]Data are least mean squares of 40 gilts, with 8 animals per treatment, analyzed using the Mixed procedure of SAS®

[2]Corn-soy based diet

[3]Control plus 6% each of corn DDGS, corn germ meal, and wheat middlings, and NE equal to the control diet

[4]Const-18, without fat added, NE content lower than Control diet

[5]Control plus 12% each of corn DDGS, corn germ meal, and wheat middlings, and NE equal to the control diet

[6]Const-36, without fat added, NE content lower than control diet

CHAPTER IV

SUMMARY AND CONCLUSIONS

Energy systems attribute a determined energy concentration to diets or ingredients based in energy utilization. The ME system is widely used in North America; however, the NE system is gaining attention based on estimated usable energy. The NE system advantage is reflected in a superior ability to rank feed ingredients according to their usable energy content, and thus potentially achieve better prediction of growth performance. Prediction equations to estimate ingredient or dietary energy concentrations have been proposed in order to simplify the process of obtaining energy values.

The approach of this thesis work was to evaluate the NE system proposed in the NRC (2012). Methodology was based on testing diets with different inclusion and proportion of ingredients when a constant energy value was formulated. As anticipated by Patience (2012), differences in growth performance between the NE and the ME system were difficult to prove. Both The ME and the NE formulated diets were able to result in equal growth performance at the whole BW level when co-product ingredients (high in fiber) were added. However, poorer carcass characteristics were observed independently of the energy system used. Unlike results under the ME system, the NE system indicated that the decrease in these carcass parameters could be the result of lower energy intake, showing itself to be more reliable in explaining energy utilization.

The digestion of diets containing increasing levels of co-products and formulated to a constant or declining NE concentration provided an expected equivalence of DE, ME and NE concentration, again supporting the ability of the NE system to accurately predict energy

utilization. However, nitrogen retention was not maintained in constant NE formulated diets, an unexpected outcome. This response may be related to an inadequate amino acid supply, to errors in the equations used to estimate NE or to the dynamics of protein synthesis regarding energy availability. The NE system plays an equal or better role than the ME system.

In conclusion, the NE system has been proven to successfully detect energy utilization when it was tested for growth performance, caloric efficiency and carcass characteristics. The NE system was able to mimic energy utilization from the determination of DE, ME and further calculation of NE. Additionally, in no instance was the ME system superior to the NE system. However, the effectiveness of the NE system to result in equal nitrogen retention could not be satisfied.

Future research on the NE system needs to refine or provide energy values for ingredient sources for swine in North America, especially ingredients that provide a significant amount of energy like fat sources.

Literature Cited

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